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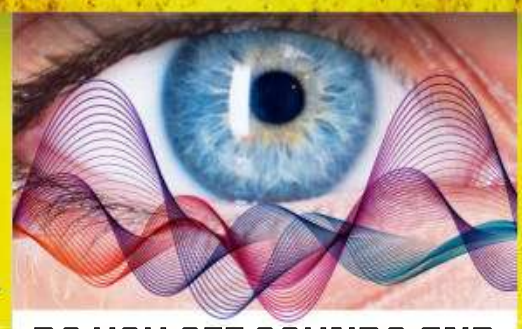

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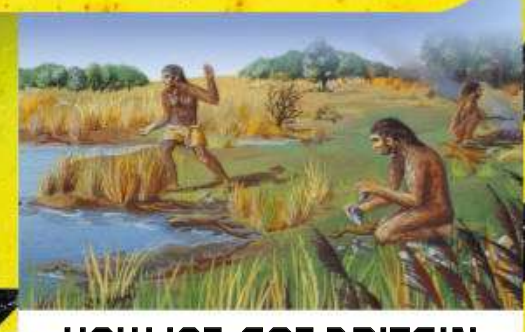

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FUTURE
ISSUE 159

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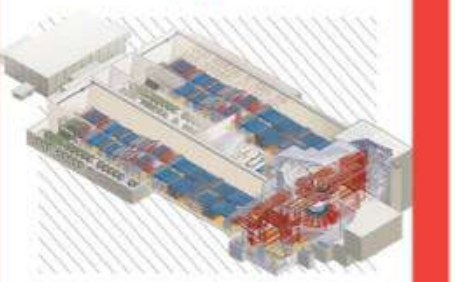
HIGHLIGHTS



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**World's biggest laser**
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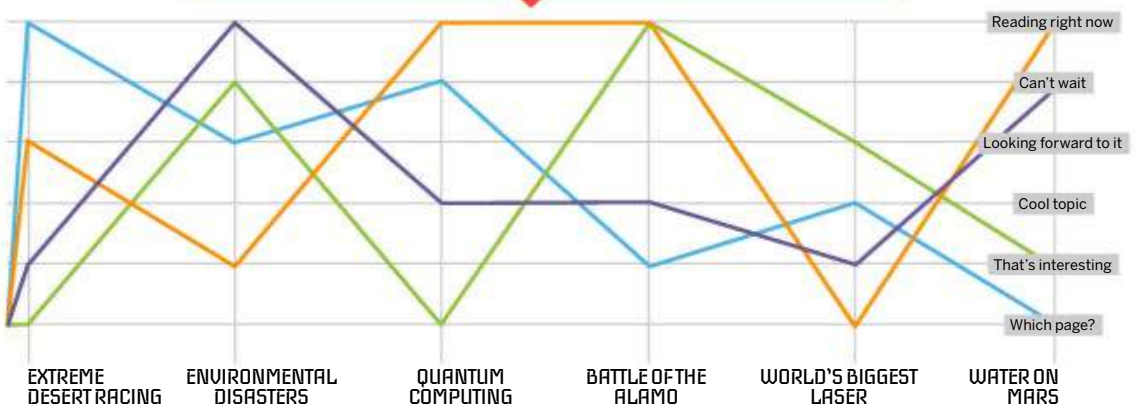
Way back in 1958, when a paper proving the scientific concept of the laser was first published, not many people thought the device would have much practical use. Fast forward over 60 years and a technophile's dreamland of applicable laser technologies later and we land on the National Ignition Facility's monstrous 1.9-megajoule powerhouse. Enormous in every sense, the NIF laser recently smashed its own record by generating 10 quadrillion watts of fusion power in a fraction of a second. It's a cool marriage of science and engineering, but what's it for? In this issue of **How It Works**, discover why scientists at NIF are trying to make a tiny star and why this could be vital to our future and all life on Earth. Enjoy!

**Ben Biggs**
EDITOR

WHAT WE'RE ANTICIPATING



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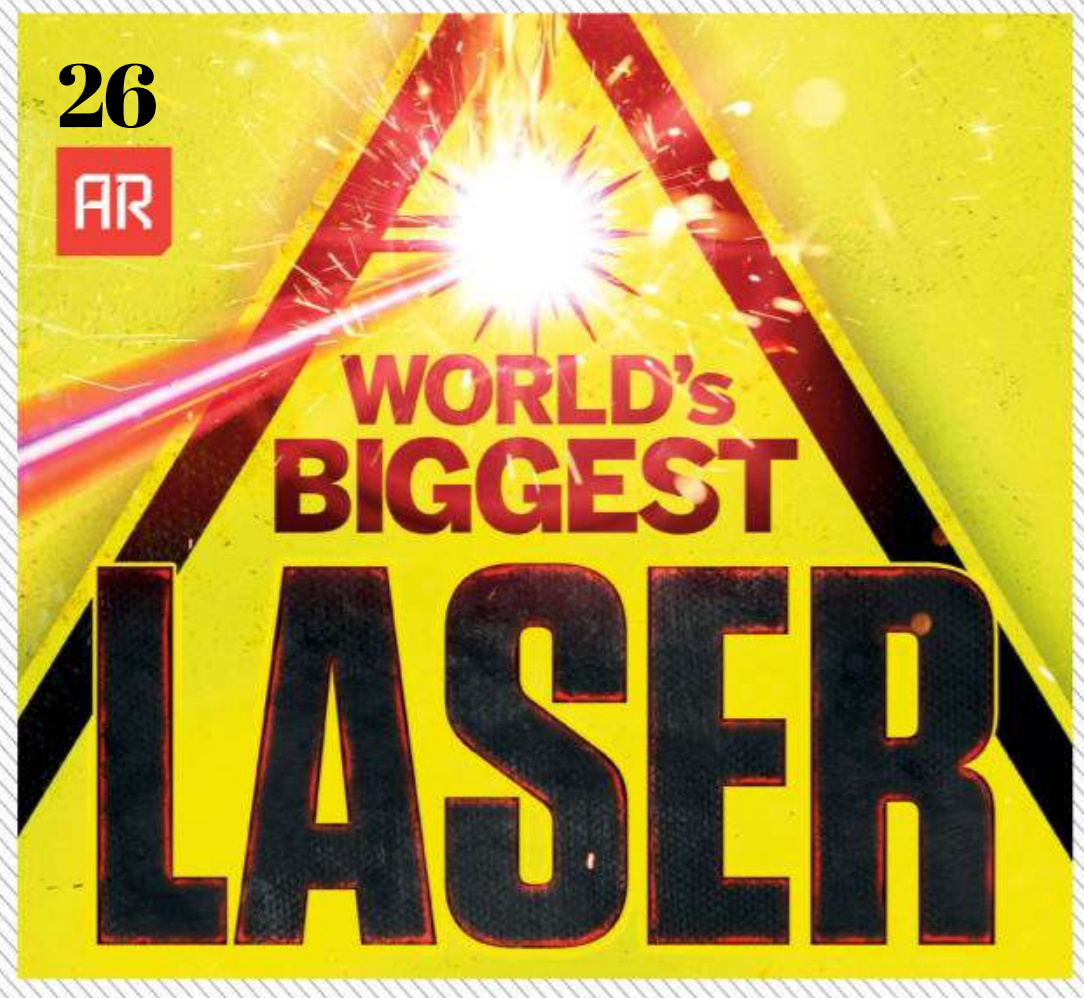



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## MEET THIS ISSUE'S EXPERTS

**ANDY EXTANCE**
Andy is a science writer. He previously worked in early stage drug discovery research, followed by a brief stint in silicone adhesive and rubber manufacturing.

**DR ANDREW MAY**
Andrew has a PhD in astrophysics and 30 years in public and private industry. He enjoys space writing and is the author of several books.

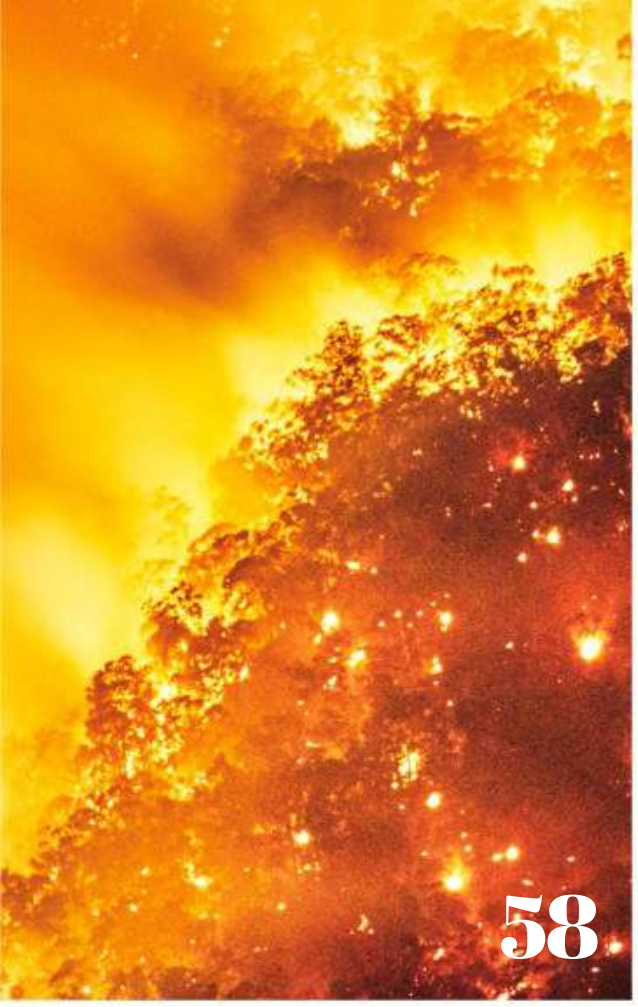
**VICTORIA WILLIAMS**
Evolutionary biologist and science writer Vicky is fascinated by the natural world and is happiest when she's in the outdoors.

**JO ELPHICK**
Jo is an academic lawyer and lecturer specialising in criminal law and forensics. She is also the author of a number of true crime books.

**MIKE JENNINGS**
Mike is a freelance technology journalist who is fascinated with gaming, futuristic technology and motorsport. He dreams of becoming a rally driver.

**JAMES HORTON**
James has a PhD in evolutionary biology and works primarily in microbiology. He's an experienced science journalist, having written for a number of science magazines.

**MARK SMITH**
A technology and multimedia specialist, Mark has written tech articles for leading online and print publications for many years.



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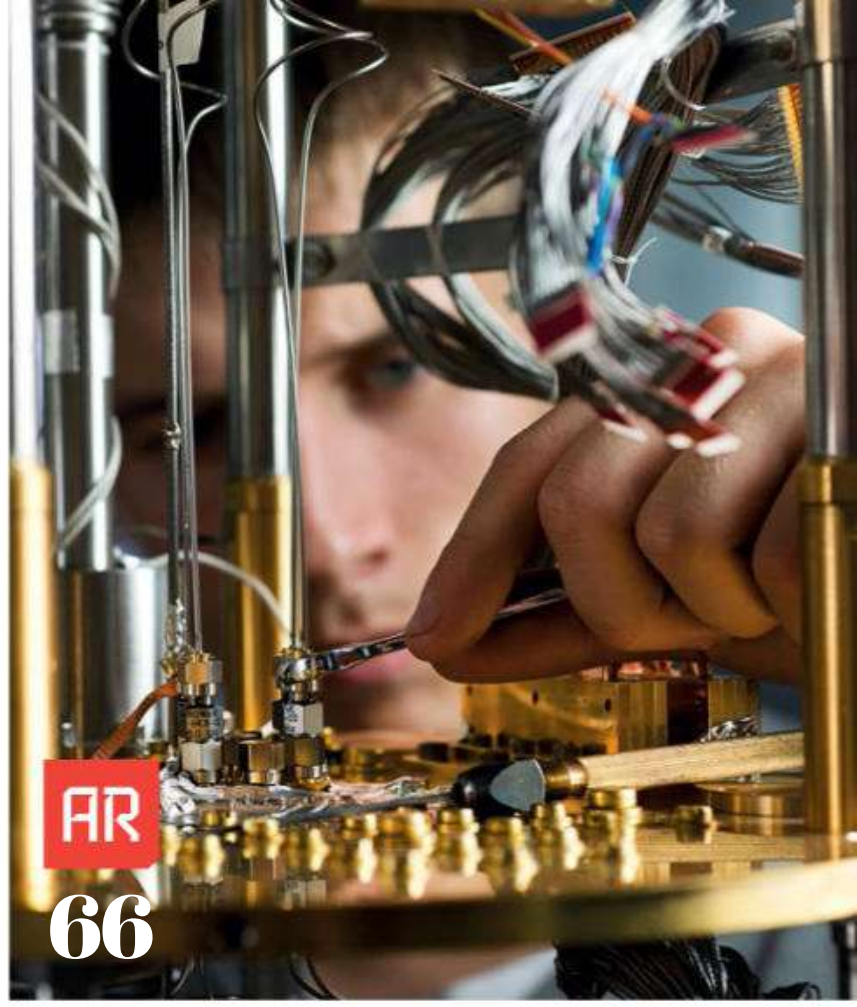

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## WIN

TWO CHILDREN'S SMARTWATCHES

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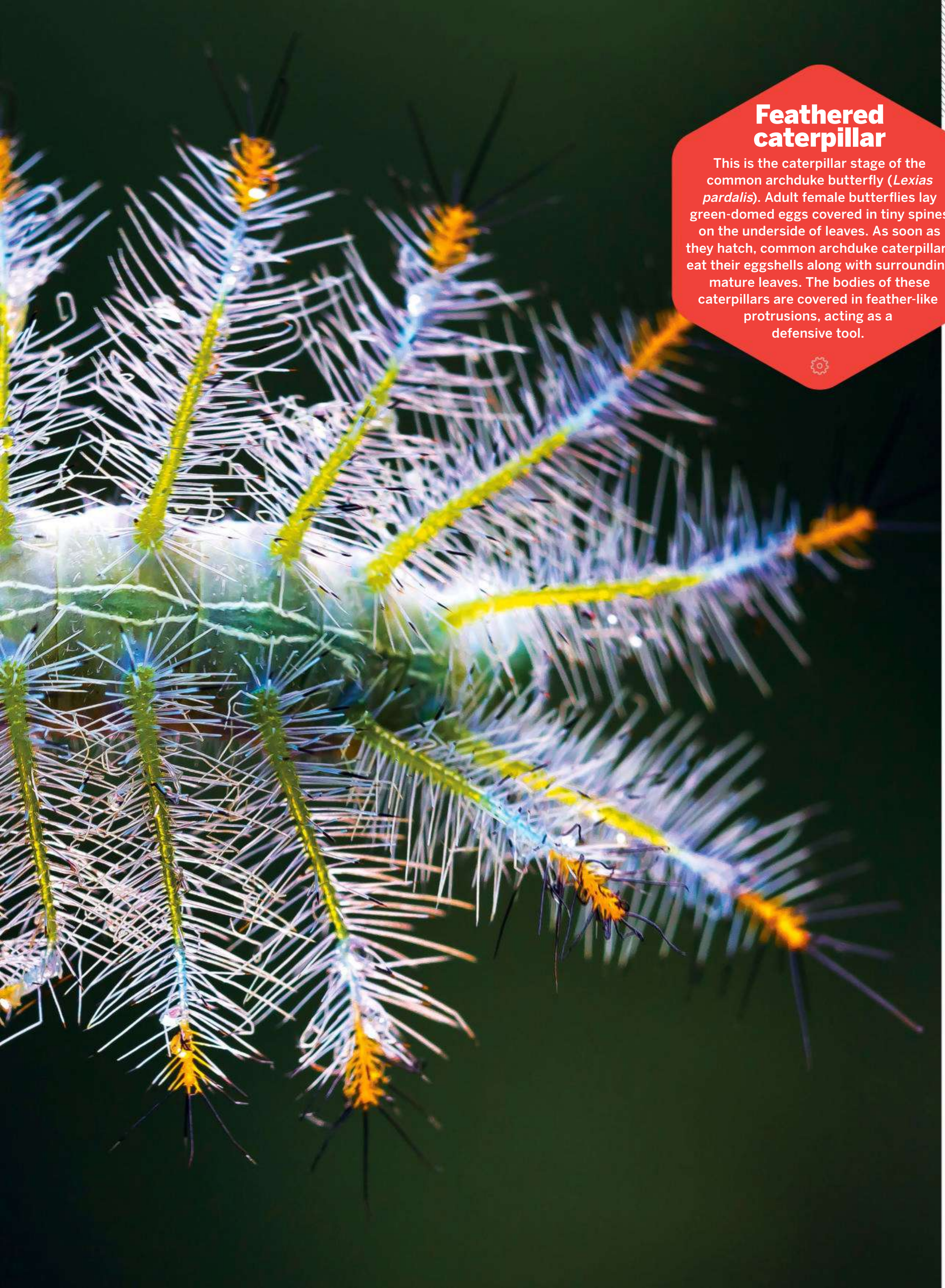

## Feathered caterpillar

This is the caterpillar stage of the common archduke butterfly (*Lexias pardalis*). Adult female butterflies lay green-domed eggs covered in tiny spines on the underside of leaves. As soon as they hatch, common archduke caterpillars eat their eggshells along with surrounding mature leaves. The bodies of these caterpillars are covered in feather-like protrusions, acting as a defensive tool.

© Getty

## Cat's tongue

This is the surface of a domestic cat's tongue. Coating the surface are hundreds of backwards-facing keratin spines, called filiform papillae. Cats spend around 24 per cent of their time grooming, and these spiny papillae make easy work of extracting hairs. The shape of these papillae has largely been described as a solid cone, but in 2018 researchers discovered that the papillae are scoop-shaped.

© Getty

## Shaping Mount Mayon

Mount Mayon is located on Luzon, the Philippines, and towers 2,463 metres into the sky. It is a stratovolcano, which are conical and are composed of hardened lava, tephra (ejected volcanic rock) and volcanic ash. Due to the high level of viscosity of the lava, it doesn't travel from the site of the eruption. Over time, the accumulation of lava builds the steep-sloped sides of the volcano.

© Getty

## Carbon star

A carbon star is a luminous type of red giant that has a carbon-rich atmosphere. When carbon stars like CW Leonis run out of hydrogen fuel in their cores, the ability to balance their own gravity and outward pressure disappears, and they start to erupt and collapse. The orange glow emitting from CW Leonis is the superhot carbon-rich dust surrounding it, which is being tossed away from the collapsing core.

© ESA/Hubble & NASA, T. Ueta, H. Kim

SPACE

# Ferris-wheel-sized chunk of the Moon is orbiting suspiciously close to Earth

WORDS BRANDON SPECKTOR

A small asteroid orbiting close to Earth could be a fragment of the Moon that snapped off during an ancient impact, new research finds. If confirmed, that would make the asteroid the first near-Earth object with a known lunar origin; this could help shed light on the chaotic history of our planet and its pockmarked companion.

The asteroid in question is called Kamoʻoalewa, a Hawaiian word that roughly means 'the oscillating celestial fragment', and was discovered in 2016 by astronomers using the Pan-STARRS telescope in Hawaii. Though the object is about 4 million times fainter than what humans can see with the naked eye, every April the rock's orbit brings it close enough to Earth that it becomes briefly visible to our most powerful telescopes. In this case, 'close enough' means about 9 million miles from Earth, or nearly 40 times the distance between Earth and the Moon. Observations showed that the asteroid measures about the size of a Ferris wheel, with a diameter of no more than 58 metres.

Because of its near-Earth orbit, Kamoʻoalewa fits into a category of celestial objects called quasi-satellites – these are essentially objects that orbit the Sun, but stay pretty close to Earth. Astronomers have detected plenty of quasi-satellites before, but they have a hard time studying them in detail given the objects' typically small sizes and incredible dimness.

The origins of such tiny travellers are hard to pin down, but the authors of a new paper made an attempt to uncover Kamoʻoalewa's secrets by studying the faint patterns of reflected light on its surface. Using the Large Binocular Telescope on a mountaintop in southern Arizona, the researchers watched Kamoʻoalewa closely during its regular April visits for several years. They found that the asteroid's light spectrum matched that of lunar samples from NASA's Apollo missions almost perfectly, suggesting the Ferris-wheel-sized boulder may be a loose piece of lunar debris. Furthermore, the asteroid's orbit, which is incredibly similar to Earth's, is atypical of the rocks that make their way towards our planet from the outer Solar System. It seems more likely that the rock has been near us for a long time.

"It is very unlikely that a garden-variety near-Earth asteroid would spontaneously move into a quasi-satellite orbit like Kamoʻoalewa's," said Renu Malhotra, a planetary sciences professor at the University of Arizona.

If Kamoʻoalewa is a piece of the smashed-up lunar surface, it's unclear what exactly kicked it loose, or how it ended up in its current orbit; no near-Earth object with a lunar origin has ever been detected before. However, after analysing the rock's orbit, researchers have found three other near-Earth asteroids with similar enough orbital patterns that they could be considered 'companions' to Kamoʻoalewa; all of the rocks may have been ejected into space during the same ancient lunar impact.

An artist's impression of Earth quasi-satellite Kamoʻoalewa near the Earth-Moon system

The lowest part of Earth's atmosphere has been rising by at least 50 metres per decade since 1980

PLANET EARTH

## EARTH'S LOWER ATMOSPHERE IS EXPANDING

WORDS **BEN TURNER**

**Earth's atmosphere is rising because of climate change. Weather balloon measurements taken in the Northern Hemisphere over the past 40 years reveal that the lowest layer of Earth's atmosphere, the troposphere, has been expanding upwards at a rate of roughly 50 metres per decade, and climate change is the cause.**

**The troposphere is the layer of the atmosphere we live in. It extends from sea level to a height ranging from 4.3 miles above the poles to 12.4 miles over the tropics. As the layer of atmosphere that contains the most heat and moisture, it's also where a lot of atmospheric weather occurs. Air in the atmosphere expands when it's hot and contracts when it's cold, so the troposphere's upper boundary, called the tropopause, naturally shrinks and expands with the seasons. But by analysing atmospheric data such as pressure, temperature and humidity, taken between 20 and 80 degrees north latitude, and pairing it with GPS data, researchers showed that as increasing quantities of greenhouse gases trap more heat in the atmosphere, the tropopause is rising higher than ever before.**

**What's more, the rate of the rise seems to be increasing. While the tropopause rose roughly 50 metres per decade between 1980 and 2000, that increase rose to 53.3 metres per decade between 2001 and 2020.**

ANIMALS

# Triassic skulls unearthed in Greenland reveal 'cold bone' dinosaur

WORDS **LAURA GEGGEL**

A huge dinosaur that roamed Greenland 214 million years ago is a new species, making it the first of its kind to reach such high northern latitudes on the now partially frozen island. Two newly described dinosaur skulls, which were unearthed 27 years ago but misclassified, belong to a new species of two-legged sauropodomorph, a group that includes the predecessors of the largest dinosaurs ever to walk the planet. Palaeontologists named the beast Issi saaneq, which means 'cold bone' in Kalaallisut, an Inuit language spoken in Greenland. Cold bone is a reference to Greenland's current climate, but when Issi was alive during the late Triassic, Greenland was part of the fracturing Pangaea supercontinent, so its home would have fallen well inside the humid temperate belt of the supercontinent.

Around that time, the Atlantic Ocean was forming as Pangaea broke into two supercontinents: Laurasia in the Northern Hemisphere and Gondwana largely in the Southern Hemisphere. Cold bone's unique location in Greenland makes it the first sauropodomorph to reach the northernmost parts of Laurasia. Researchers originally discovered the skulls in 1994 during an excavation in Jameson Land, a peninsula in East Greenland. But in a fumble, palaeontologists wrongly attributed one of the skulls to *Plateosaurus trossingensis*, a long-necked dinosaur known from the Triassic Period of Germany, France and Switzerland. A new study, which rights that wrong, found that the skulls belong to a sister group of the *Plateosaurus* genus. "It's exciting to discover a close relative of the well-known *Plateosaurus*, hundreds of which have already been found here in Germany," said Oliver Wings, a vertebrate palaeontologist at Martin Luther University of Halle-Wittenberg in Germany.

**Did you know?** Over 700 dinosaur species have been named

Based on its skull anatomy, I. saaneq was a medium-sized, long-necked herbivore in the plateosaurid group, whose members were long-necked dinosaurs in what is now Brazil and Europe that reached lengths of three to ten meters. However, neither of the two skulls belonged to a mature adult; one belonged to a juvenile, and the other was from a late-stage juvenile or a young adult. A micro-CT scan allowed scientists to create virtual 3D models of both skulls.

The newly named dinosaur Issi saaneq, which lived in Greenland 214 million years ago

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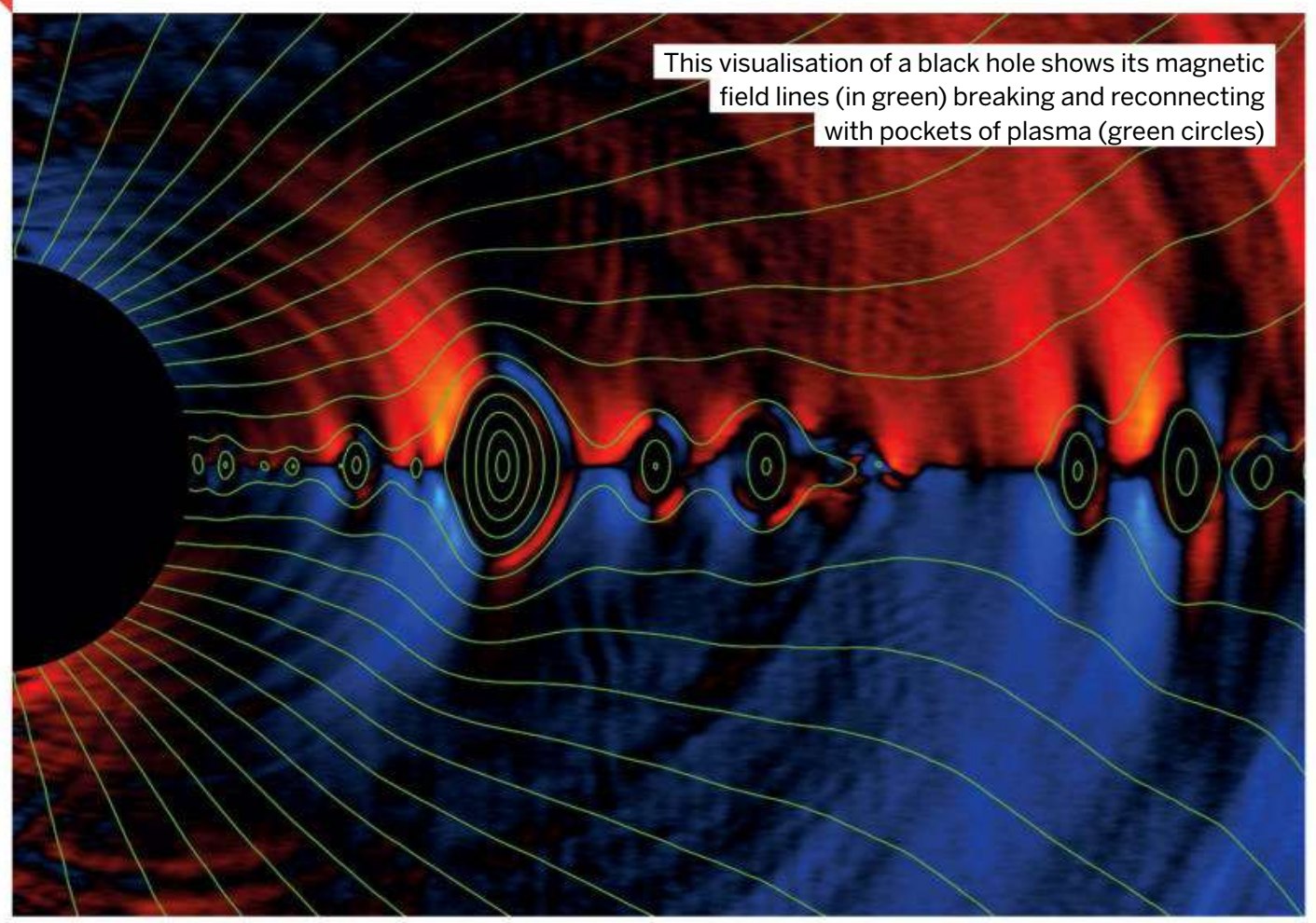


This visualisation of a black hole shows its magnetic field lines (in green) breaking and reconnecting with pockets of plasma (green circles)

SPACE

# ‘Balding’ black holes prove Einstein right again on general relativity

WORDS CHELSEA GOHD

A new physics breakthrough shows how Einstein’s theory of general relativity continues to hold up, even for ‘balding’ black holes. Black holes are regions of space-time where gravity’s pull is so strong that nothing, not even light, can escape from being dragged in and ‘eaten’.

Einstein’s theory of general relativity predicted the existence of black holes and that no matter what such an object ‘eats’, black holes are characterised only by their mass, spin and electrical charge. Astrophysicists refer to this as the ‘no-hair’ theorem. But there has been a lingering snag to this theorem: magnetic fields. For the no-hair theorem to hold true, ‘eating’ material shouldn’t alter a black hole’s primary characteristics. But while black holes can be ‘born’ with strong magnetic fields, they can also gain them by ‘eating’ certain material, and clouds of plasma can sustain these magnetic fields around a black hole.

Physicists investigated this snag by using a supercomputer to simulate a black hole surrounded by plasma. In this study, they found that even when black holes have sustained magnetic fields, the ‘no-hair’ theorem, and therefore Einstein’s theory, continue to hold true. “The no-hair conjecture is a cornerstone of general relativity,” said Bart Ripperda, a research fellow at the Flatiron Institute’s Center for Computational Astrophysics (CCA) in New York City and a postdoctoral fellow at Princeton University in New Jersey. “If a black hole has a long-lived magnetic field, then the no-hair conjecture is violated. Luckily, a solution came from plasma physics that saved the no-hair conjecture from being broken.”

In their simulations, the researchers found that magnetic fields around black holes can evolve. Their simulations showed that magnetic field lines around the black hole would quickly break apart and reconnect. This phenomenon created pockets of plasma, energised by the magnetic field, that would bubble up and either be ejected out into space or swallowed up by the black hole.

“Theorists didn’t think of this because they usually put their black holes in a vacuum,” Ripperda says. “But in real life there’s often plasma, and plasma can sustain and bring in magnetic fields. And that has to fit with your no-hair conjecture.” What really rescued the no-hair theorem, however, is that the scientists found that this process quite quickly drained the magnetic field until it completely faded away. This depletion happened very fast, at a rate of ten per cent the speed of light. “The fast reconnection saved the no-hair conjecture,” Ripperda said.

HEALTH

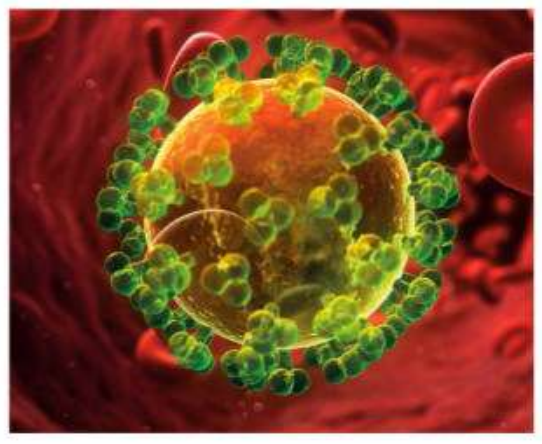
# PATIENT’S IMMUNE SYSTEM CURES HIV

WORDS JOANNA THOMPSON

**In 2013, doctors delivered a life-altering diagnosis to a woman in Argentina: she had HIV, the virus that causes AIDS. Eight years later, the virus has all but disappeared from her system. In fact, stunned researchers were unable to find evidence of any HIV viral particles in her body, “despite analysis of massive numbers of cells from blood and tissues, suggesting that this patient may have naturally achieved a sterilising cure,” researchers wrote.**

**This represents the second known case of a person’s immune system eliminating HIV without a bone marrow transplant or drug intervention. The first such case was a California woman named Loreen Willenberg, who in 2020 found out that the virus was absent from her body for the first time in 27 years. Just two other people, pseudonymously known as the London Patient and the Berlin Patient, have ever been cured of HIV, but only after having their immune cells completely replaced via stem cell therapy.**

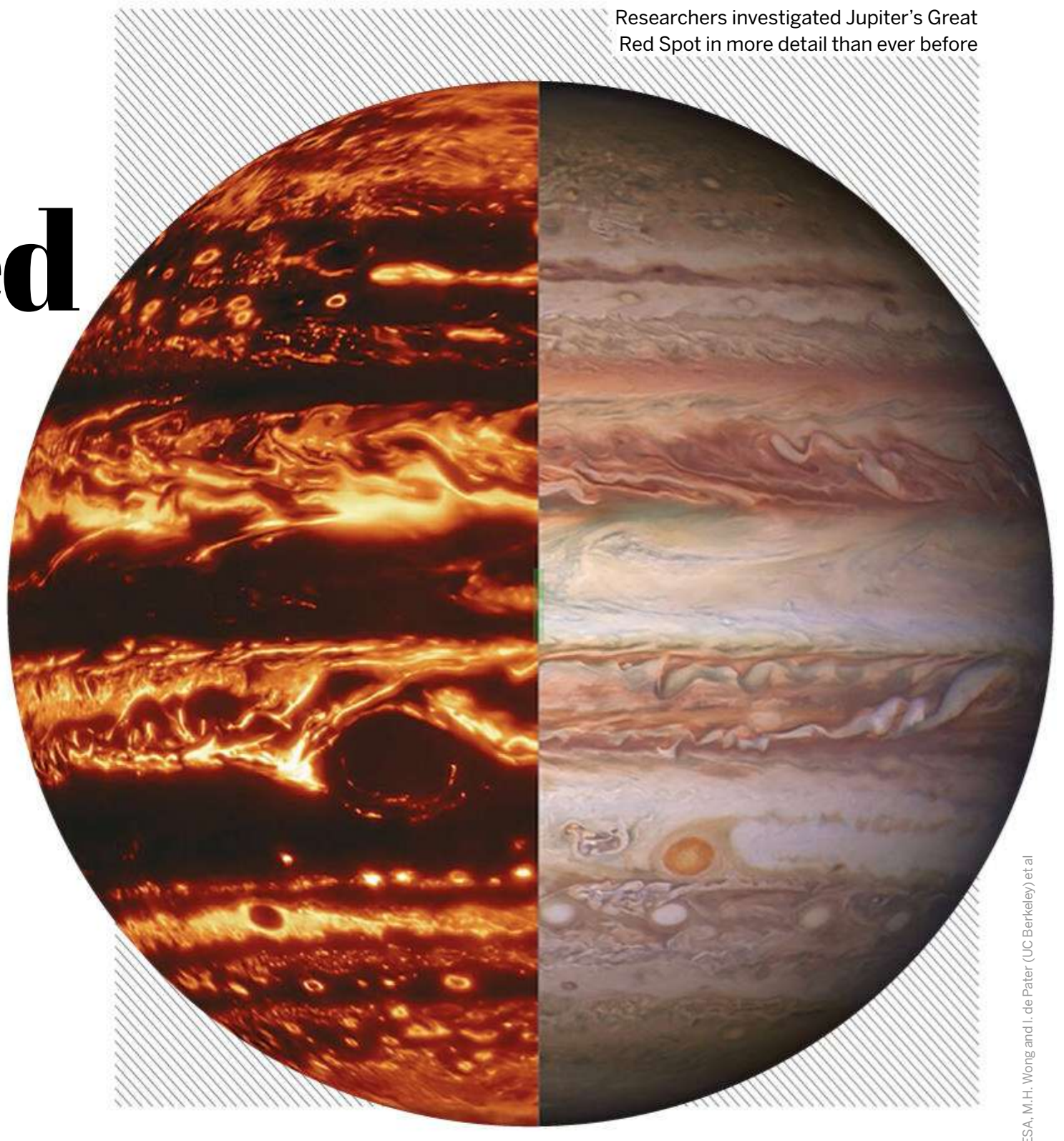
**The Argentine woman was dubbed the ‘Esperanza Patient’ by her doctors in order to protect her anonymity in a country where people are still stigmatised for HIV-positive status. Medical professionals say that she belongs to a rare group of HIV patients called ‘elite controllers’. Although the virus is present in their systems, they are able to maintain a low enough viral load that they don’t develop symptoms, even without treatment.**



An artist’s illustration of the HIV virus

SPACE

# Jupiter's Great Red Spot is 40 times deeper than the Mariana Trench



Researchers investigated Jupiter's Great Red Spot in more detail than ever before

© Getty / A. Bransgrove et al. Physical Review Letters 2021 / International Gemini Observatory/NOIRLab/NSF/AURA/NASA/ESA, M.H. Wong and I. de Pater (UC Berkeley) et al

WORDS **BRANDON SPECKTOR**

On Jupiter, a storm's been brewing for more than 300 years. Known as the Great Red Spot, this swirling high-pressure region is clearly visible from space, spanning a region in Jupiter's atmosphere more than 10,000 miles wide – about one-and-a-quarter times the diameter of Earth. But there's even more to the churning tempest than meets the eye; Jupiter's Great Red Spot is also extraordinarily deep, extending as many as 300 miles into the planet's atmosphere, or about 40 times as deep as the Mariana Trench on Earth.

That's far deeper than researchers expected, with the bottom of the storm extending well below the atmospheric level where water and ammonia are expected to condense into clouds. The storm's deep roots suggest that some as-yet-unknown processes link Jupiter's interior and deep atmosphere, driving intense meteorological events over much larger scales than previously thought. "We're getting our first real understanding of how Jupiter's beautiful and violent atmosphere works," said Scott Bolton, principal investigator of NASA's Juno mission.

Two new studies relied on observations from NASA's Juno probe, which entered Jupiter's orbit in 2016 and has since completed 36 passes of the nearly 87,000-mile-wide gas giant. In one study, scientists examined the Great Red Spot using the probe's microwave radiometer, a tool that detects microwaves emitted from inside the planet. Unlike the radio and infrared radiation emitted by the gas giant, microwaves can make it all the way through the planet's thick cloud layer.

By studying the microwave emissions that made it through the Great Red Spot, researchers of the first study determined that the storm extends more than 200 miles deep. But the second study found that the spot may be even bigger than that. Researchers examined the Great Red Spot using Juno's gravity detection tools. Synthesising data from 12 flights that passed by the spot, including two direct overhead flights, the researchers calculated where the storm was concentrating the most atmospheric mass over the planet, allowing them to estimate its depth. The authors determined that the Great Red Spot reaches a maximum depth of about 300 miles below the cloud tops.

As deep as this seems, the Great Red Spot is still much shallower than the enormous jets of wind that surround and power it; those bands of wind extend to depths of about 2,000 miles below the cloud tops. The reasons for this discrepancy remain a puzzle, but the spot's relative shallowness might be due to another recently discovered phenomenon: the Great Red Spot is shrinking, having lost about one-third of its width since 1979.

**Did you know?**
Juno was Jupiter's wife in Greek mythology

PLANET EARTH

# Diamond hauled from deep inside Earth holds never-before-seen mineral

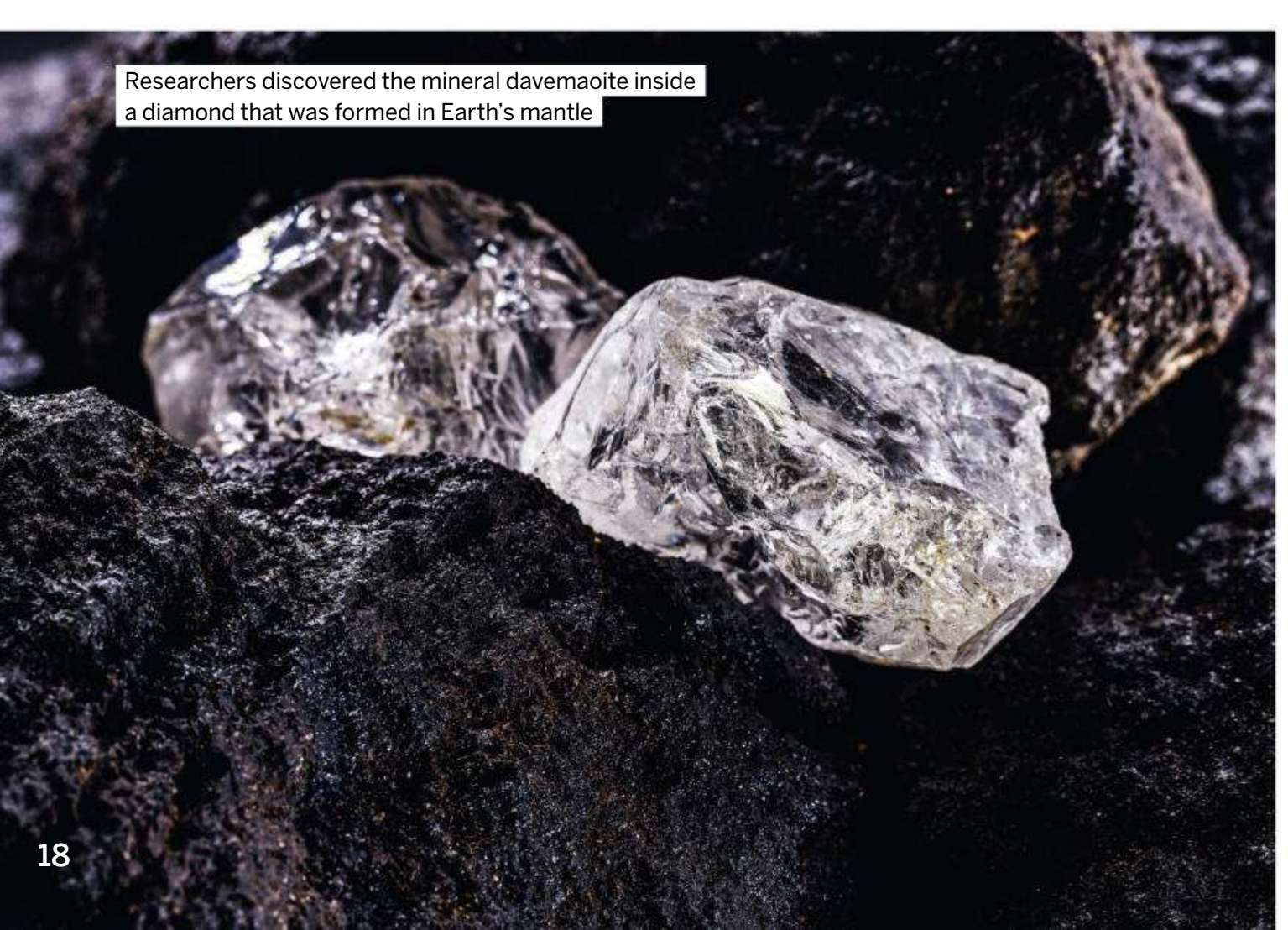
WORDS **HARRY BAKER**

Within a diamond hauled from deep beneath Earth's surface, scientists have discovered the first example of a never-before-seen mineral. Named davemaoite after prominent geophysicist Ho-kwang (Dave) Mao, the mineral is the first example of a high-pressure calcium silicate perovskite ($CaSiO_3$) found on Earth. Another form of $CaSiO_3$, known as wollastonite, is commonly found across the globe, but davemaoite has a crystalline structure that forms only under high pressures and temperatures in Earth's mantle, the mainly solid layer of Earth trapped between the outer core and the crust.

Davemaoite has long been expected to be an abundant and geochemically important mineral in Earth's mantle. But scientists have never found any direct evidence of it because it breaks down into other minerals when it moves towards the surface and pressure decreases. Analysis of a diamond from Botswana, which formed in the mantle around 410 miles below Earth's surface, has revealed a sample of intact davemaoite trapped inside. The International Mineralogical Association has confirmed davemaoite as a new mineral. "The discovery of davemaoite came as a surprise," said Oliver Tschauner, a mineralogist at the University of Nevada, Las Vegas.

Tschauner and his colleagues uncovered the davemaoite sample with a technique known as synchrotron X-ray diffraction, which focuses a high-energy beam of X-rays on certain spots within the diamond with microscopic precision. By measuring the angle and intensity of the returning light, researchers can decipher what's inside, Tschauner said. The sample of davemaoite within the diamond was just a few micrometres in size, so less powerful sampling techniques would have missed it, he added. Davemaoite is believed to play an important geochemical role in Earth's mantle. Scientists theorise that the mineral may also contain other trace elements, including uranium and thorium, which release heat via radioactive decay. Therefore davemaoite may help to generate a substantial amount of heat in the mantle.

**Did you know?**
Diamonds were first uncovered in India



Researchers discovered the mineral davemaoite inside a diamond that was formed in Earth's mantle

HEALTH

## DRUG TO TREAT GENETIC CAUSE OF DWARFISM APPROVED

WORDS **NICOLETTA LANESE**

**The Food and Drug Administration (FDA) has approved the first drug to treat the most common form of dwarfism, achondroplasia. This is caused by mutations in the FGFR3 gene, which encodes instructions to build a protein involved in bone growth and development. These mutations push the gene into overdrive, impeding the process by which cartilage tissue gets replaced by bone; this leads to the development of short and abnormally shaped bones and causes people with achondroplasia to be of short stature.**

**BioMarin Pharmaceutical has been developing and testing a treatment for years. Now that drug has officially been approved for use in children ages five and up. Clinical trials suggest that the drug, Voxzogo, is safe and effective at restoring bone growth in children with achondroplasia – thus boosting height – but it's unclear whether the drug also counteracts the various health issues that can come with the condition.**

**Voxzogo, also known by the generic name vosoritide, works by binding to a receptor called natriuretic peptide receptor-B that's found in bone and cartilage tissues. Once attached to this receptor, the drug sets off a chain reaction that stimulates bone growth and overrides the effects of FGFR3 mutations. If treated throughout childhood, kids with achondroplasia could reach similar heights as children without the condition.**

Voxzogo is being developed by BioMarin Pharmaceutical

ANIMALS

# Polar bear parts are being smuggled around the world

WORDS **PATRICK PESTER**

The head of a stuffed polar bear, not involved in the seizures

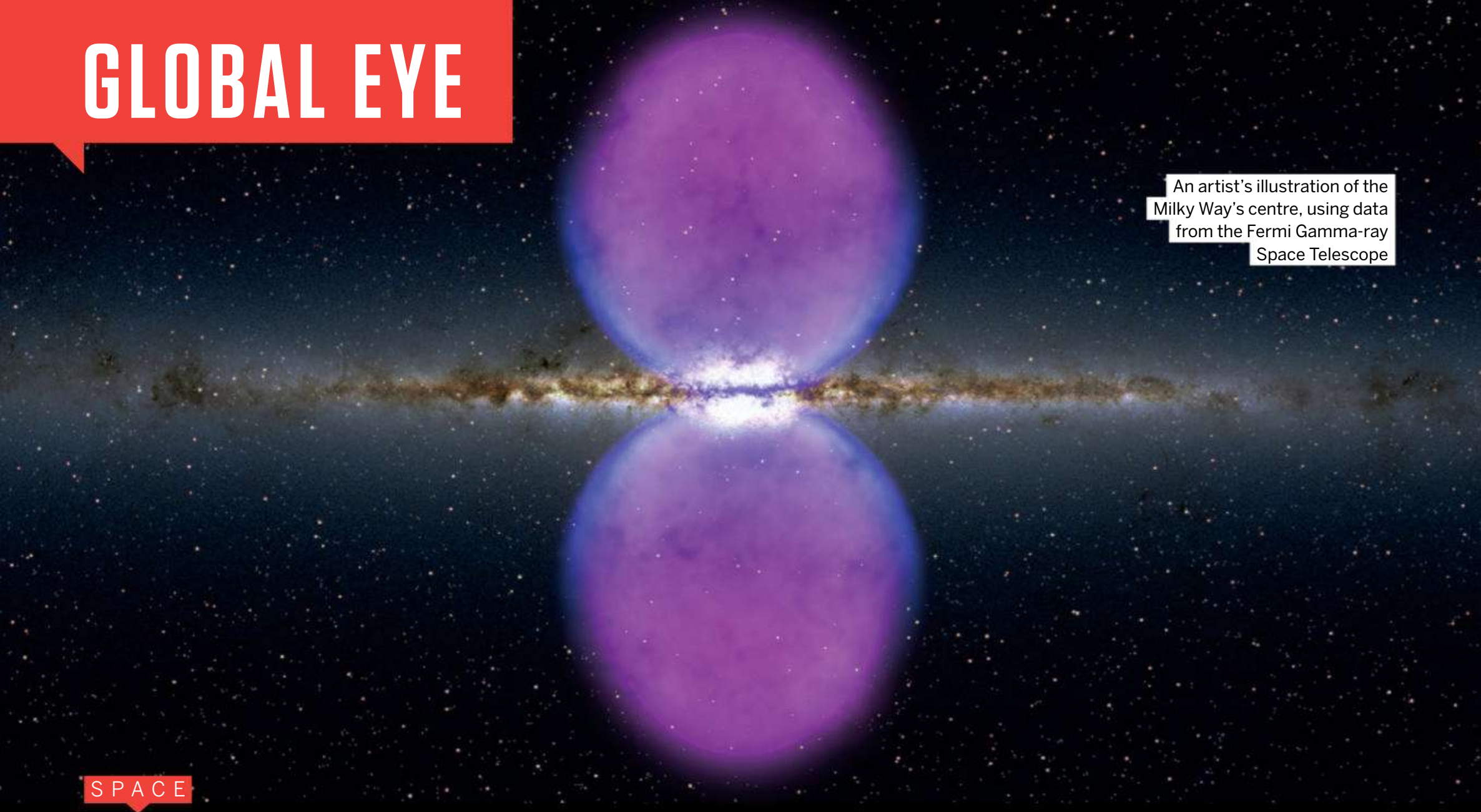
People have smuggled hundreds of bear body parts, including polar bear parts, into Australia and New Zealand. Enforcement agencies seized bear teeth, rugs, bile and embryos suspended in honey from passengers arriving in Australia and New Zealand from 2007 to 2018. Most of the bear parts and derivatives, such as gallbladder bile, were ingredients in traditional medicines. The goods were most often seized from people travelling into Australia and New Zealand from China, but they also came from other countries such as the US and Canada. "We knew we would find some records, but we never expected them to be in the hundreds or the diversity of products and number of countries from which they were being sourced and transported," said Phill Cassey, head of ecology and evolutionary biology at the University of Adelaide in Australia.

Trade in wildlife threatens many species around the world. Bears are traded for their gallbladder bile, which is used in traditional Asian medicines, as well as their meat and body parts, such as those used as hunting trophies. To gain a greater understanding of the bear trade, researchers looked at countries that don't have their own wild bears. The team found records of 781 seizures: 369 in Australia and 412 in New Zealand. They involved five of the eight bear species, and all seizures were declared for 'personal use'. The number of seizures declined in Australia during the study period, from a peak of 74 in 2011 to 12 in 2018. There was no such decline in New Zealand. Though 2009 was a peak for seizures with 52 and 2018 was a low point with 13 seizures, the overall trend was more variable than Australia, with more than 40 seizures in 2017, for example.

The items seized came from 33 countries around the world, with China being the reported origin of 37.7 per cent of seizures in Australia and 71.2 per cent of seizures made in New Zealand. The most common items seized were traditional medicines made out of bear bile. Humans obtain bear bile by killing bears or by keeping them alive in cages on bear farms, where handlers regularly extract the bile, such as through a catheter inserted into a bear's gallbladder. Bear bile contains ursodeoxycholic acid, which can be used to reduce the absorption of cholesterol and dissolve gallbladder stones in people. However, herbal and synthetic alternatives exist with the same properties, and bear bile is used to treat many conditions that it doesn't benefit, such as hangovers.

The US and Canada were the biggest source of bear body parts, such as teeth, claws and trophy heads. "North America is popular with trophy hunters," Cassey said. "Some legal hunting is still permitted in North America and Europe, and clearly Australians and New Zealanders are partaking in these activities." Travellers had legally procured some of these seized items, which were returned to them. That was the case far more often for trophies than it was for medicines, teeth and claws, the majority of which were illegal. "The illegal wildlife trade is a global problem which needs global solutions," Cassey said. "Just because Australia and New Zealand don't have any native bears doesn't mean they aren't part of the problem."

© Getty / Alamy



An artist's illustration of the Milky Way's centre, using data from the Fermi Gamma-ray Space Telescope

SPACE

# Astronomers discover a 'barrier' around the centre of the Milky Way

WORDS **BRANDON SPECKTOR**

The centre of the Milky Way may be even more bizarre than astronomers thought. In a new study, a team of researchers from the Chinese Academy of Sciences in Nanjing investigated a map of radioactive gamma rays – the highest energy form of light in the universe, which can arise when extremely high-speed particles called cosmic rays crash into ordinary matter, blasting in and around the centre of our galaxy.

The map revealed that something near the centre of the galaxy appears to be accelerating particles to mind-blowing speeds, very near the speed of light, and creating an abundance of cosmic rays and gamma rays just outside the galactic centre. However, even as the galactic centre blows a constant storm of high-energy radiation into space, something near the Milky Way's core prevents a large portion of cosmic rays from other parts of the universe from entering. The researchers described the effect as an invisible 'barrier' that is wrapped around the galactic centre and is keeping the density of cosmic rays there significantly lower than the baseline level seen throughout the rest of our galaxy. In other words, cosmic rays can get out of the galactic centre, but have a hard time getting in. How this cosmic barrier works, or why it exists, remains a mystery.

The centre of our galaxy is located about 26,000 light years from Earth in the constellation Sagittarius. It's a dense and dusty place, holding more than 1 million times as many stars per light year as the entire Solar System, all wrapped around a supermassive black hole with about 4 million times the mass of the Sun. Scientists have long suspected that this black hole, named Sagittarius A*, or perhaps some other object at the galactic centre, is accelerating protons and electrons to near light speed, creating cosmic rays that beam throughout our galaxy and onwards into intergalactic space. These rays propagate through the magnetic fields of our galaxy, creating an ocean of high-energy particles that's roughly uniform in density throughout the entire Milky Way. This steady soup of particles is called the cosmic ray sea.

**Did you know?**

Fermi was launched in June 2008

In the new study, researchers compared the density of cosmic rays in this sea to the density of cosmic rays within the galactic centre. Cosmic rays cannot be seen directly, but scientists can find them in gamma-ray maps of space, which effectively show where cosmic rays have collided with other types of matter. Using data from the Fermi Gamma-ray Space Telescope, the team confirmed that something in the galactic centre is acting as a giant particle accelerator, shooting cosmic rays out into the galaxy. Possible culprits include Sagittarius A*, as black holes could theoretically shoot certain particles into space even as they gobble up everything else around them; the remnants of ancient supernovae or even strong stellar winds from the many stars crammed into the galactic centre. But the map also revealed the mysterious 'barrier', a clear point where the density of cosmic rays drops off significantly at the edge of the galactic centre. The source of this phenomenon is harder to pinpoint, but it may involve the jumble of magnetic fields near our galaxy's dense core.

High levels of mercury were likely caused by exposure to cinnabar, used to make a bright-red paint pigment

HISTORY

# Earliest evidence of mercury poisoning in humans found in 5,000-year-old bones

WORDS YASEMIN SAPLAKOGLU

The earliest evidence of mercury poisoning has been found in 5,000-year-old bones of humans buried in Spain and Portugal. Exposure to the naturally occurring heavy metal may have toxic effects on the body, including on the nervous, digestive and immune systems. That's why the World Health Organization (WHO) considers mercury one of the top-ten chemicals of major health concern.

Today, people are most commonly exposed to some level of mercury when they eat certain fish or shellfish, though the levels are often low. But how common was mercury exposure in the olden days? To figure this out, researchers analysed human bones collected from 23 different archaeological sites – which included pits and caves – across Spain and Portugal. The bones studied belonged to 370 individuals who lived in various time periods across a span of 5,000 years.

Analysis of some of the bones, mainly the humerus, the arm bone between the shoulder and the elbow, revealed unusually high levels of mercury – levels that wouldn't have been caused by diet or by decomposition after death. The researchers detected mercury levels of up to 400 parts per million in some of the remains, which is much higher than the one or two parts per million that the WHO deems normal levels in human hair.

The researchers say the unusually high levels of mercury were likely caused by exposure to cinnabar, a toxic mercury sulphide mineral that, when ground into a fine powder, has a bright-red colour and has been historically used to produce paint pigments. In fact, one of the largest cinnabar mines in the world is in Almadén, Spain.

People started exploiting Almadén's cinnabar trove in the Neolithic period, around 7,000 years ago. The highest levels of mercury were in the remains that dated back to 2900 to 2300 BCE, or the late Neolithic to the middle Copper Age – a transition between the Neolithic and Bronze Age. At this time, cinnabar was a highly symbolic, probably sacred substance "which was sought after, traded and extensively used in a variety of rituals and social practices," researchers said.

In tombs dating back to this time period found in southern Portugal and Andalusia, cinnabar powder was used to paint chambers, decorate figurines and even spread over the dead. It's possible that people could have accidentally, or deliberately for reasons related to rituals, inhaled or consumed large amounts of mercury-filled cinnabar. By the end of the Copper Age and start of the Bronze Age, around 2200 BCE, the use of cinnabar decreased significantly.

ANIMALS

# FISH RUB UP AGAINST GREAT WHITE SHARKS

WORDS YASEMIN SAPLAKOGLU

**Fish keep their friends close, and their enemies closer... but only because they need to exfoliate. Researchers recently discovered that different species of fish use sharks as scrub brushes by pushing up against the sea predators' scaly bodies to get rid of parasites and other irritants. Though this dangerous behaviour has been observed before, it wasn't clear just how common it was. Lacey Williams and Alexandra Anstett, graduate students at the University of Miami, first observed this behaviour with drones while collecting data on great white sharks (*Carcharodon carcharias*) in Plettenberg Bay, South Africa. But it wasn't until they saw this same chafing behaviour in a social media post from the Atlantic White Shark Conservancy that they realised that their observations weren't an isolated incident.**

**To figure out just how common this behaviour is, the researchers compiled data from photos, videos, drone footage and witness reports and discovered 47 total instances of fish rubbing against sharks in 13 different locations across the world.**

**They observed this phenomenon across 12 different fish species and eight shark species. For example, leerfish (*Lichia amia*) scrub themselves using the rough skin of great white sharks, silky sharks (*Carcharhinus falciformis*) and whale sharks (*Rhincodon typus*). The number of exfoliating fish varied from one to over 100 individuals at a time.**

Fish bravely use sharks' rough skin to clean themselves

© NASA's Goddard Space Flight Center / Getty

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The FMC multilayer broadband film and BAK4 prisms are designed for exceptional low-light performance, which is great for watching sunsets – or sunrises, if your youngster is an early bird – but take care not to look directly at the Sun! These deceivingly powerful binoculars are the perfect pocket companion for outdoor excursions, no matter the time of day.

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For the naturally curious child in your household, Promora's binoculars for kids come with a complete explorer's kit. In addition to the preschool-friendly 8x binoculars, your little one also gets a magnifying glass, compass with clippable carabiner and a handy carrying bag for their next woodland adventure. From hiking and camping to beginner birdwatching, your child will feel like a true outdoorsperson with the adjustable central axis and central focusing wheel. The comfortable rubber eyepieces include a diopter knob as well, ensuring high-resolution close ups. Some reviewers reported not-so-kid-resistant build materials, but you're still sure to get your money's worth from this all-inclusive set.

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Why America's National Ignition Facility is recreating the conditions that exist inside stars

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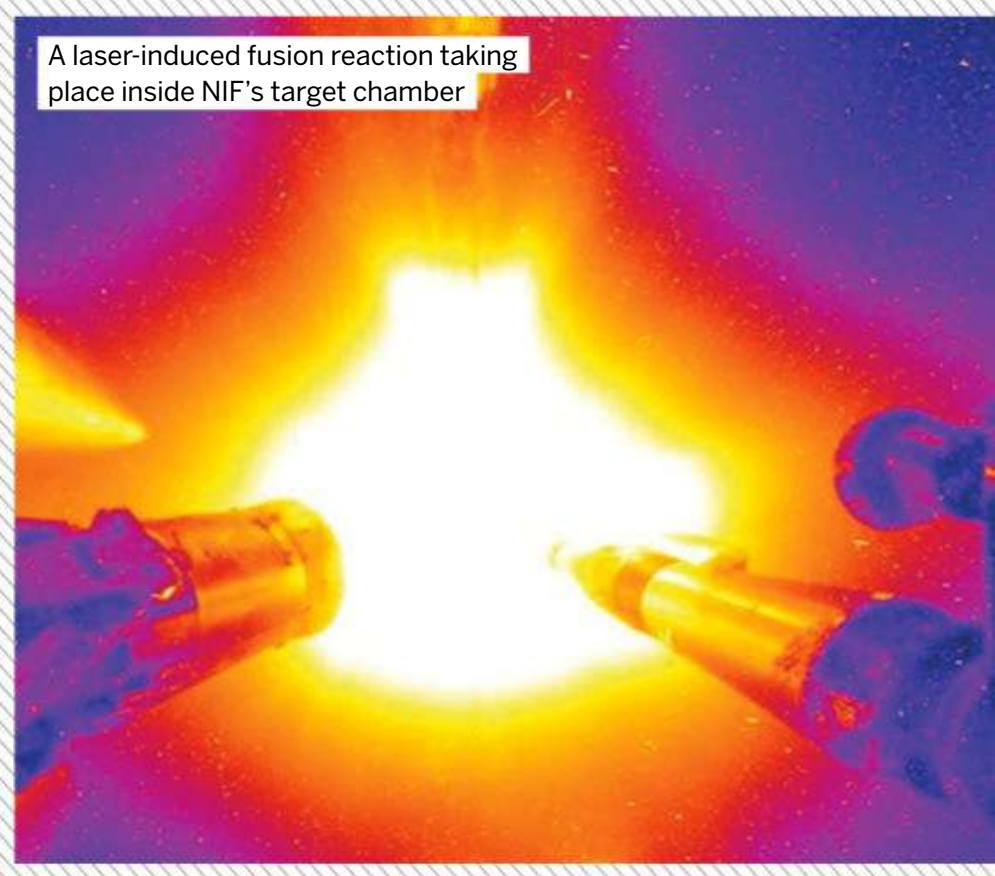
# THE WORLD'S BIGGEST LASER

WORDS **ANDREW MAY**

**DID YOU KNOW?** NIF was used as a set in the 2013 movie *Star Trek Into Darkness*, representing a starship's warp core

The heart of NIF is the target bay, where all the laser beams converge



A laser-induced fusion reaction taking place inside NIF's target chamber

# Why America's National Ignition Facility is recreating the conditions that exist inside stars

If someone told you there's a giant laser in California that has something to do with space and national defence, you might imagine it was a super-weapon designed to blast enemy satellites out of the sky. But the reality is quite different. The laser is a unique research tool for scientists, capable of creating the extreme conditions that exist inside stars and nuclear explosions.

The giant laser is located at the Lawrence Livermore National Laboratory (LLNL) in Livermore, California, and it goes by the rather cryptic name of the National Ignition Facility (NIF). In the context of nuclear science, 'ignition' has a very specific meaning. It refers to the point at which a fusion reaction becomes self-sustaining – a condition that's found inside the Sun and other stars, but is extremely difficult to achieve in an earthbound laboratory. Triggering nuclear fusion requires enormously high temperatures and pressures, and that's where NIF's giant laser comes in.

**Did you know?**
NIF took 12 years to build, between 1997 and 2009

Operational since March 2009, NIF fills a ten-storey building as big as three football fields. It has 192 separate laser beams, which direct all their energy onto a small target less than a centimetre in size. This happens in a single, carefully coordinated pulse lasting just a few billionths of a second. The resulting flash of light creates the extreme conditions needed for fusion to occur, including temperatures of 100 million degrees Celsius and pressures 100 billion times that of Earth's atmosphere.

To understand how NIF achieves such an astounding feat, it's worth taking a closer look at just what a laser beam is. The word laser stands for 'light amplification by stimulated emission of radiation', and that holds the key to how they work. Perhaps the most familiar example of amplification is in a sound system, where additional energy is pumped into an audio signal to make it louder while still preserving its exact characteristics so we hear the result without any distortion. That's effectively what a laser does – but with light instead of sound.

In the case of NIF, the 192 laser beams are progressively amplified as they pass back and forth through slabs of neodymium-doped phosphate glass. The energy for this amplification comes from a series of powerful flashlamps surrounding the glass slabs. Before the beams go through, the intense white light from these lamps is used to raise the neodymium atoms to higher-than-normal energy levels. Then, as a laser pulse passes through the glass, it triggers the 'stimulated emission' referred to in the laser acronym. The excess energy in the neodymium atoms is released in the form of more light waves, travelling in exactly the same direction and with exactly the same wavelength as the original pulse. Thus the laser beams are progressively amplified at each pass, eventually emerging more than a quadrillion times as powerful as when they entered.

Nuclear fusion is a reaction in which the nuclei of light atoms, such as hydrogen, combine to make heavier ones such as helium. It's essential to life on Earth because it powers the Sun, which is our primary source of light and heat. For decades scientists have endeavoured to replicate this process with a controlled, self-sustaining fusion reaction on Earth. In many ways this would be the perfect energy source, free of the radioactive waste associated with traditional nuclear power stations or the carbon emissions of fossil fuels.

© Getty / Alamy / LLNL

# HOW THE GIANT LASER WORKS

The ultimate purpose of NIF is to focus all the energy from an array of powerful laser beams onto a pea-sized target. The lasers don't fire continuously, but in a brief pulse just 20 billionths of a second long. That's enough to raise the target to the enormous temperatures and pressures the researchers need.

From the initial creation of the laser pulse to blasting the target only takes a few microseconds, but a lot happens in that time. To start with, a single weak pulse is created in the master oscillator room. This is then split into a total of 192 separate beams inside the two giant laser bays, where the beams are progressively amplified as they pass back and forth through the system. The energy for this comes from super-powerful flashlamps which illuminate a series of glass slabs through which the beams pass, constantly gaining energy as they do so.

During the amplification process the beams all travel in parallel, but once they are sufficiently powerful they are rearranged into two conical shapes inside the target chamber. These converge onto the target from above and below, all arriving at the same instant to deliver their energy in a single massive flash.

AR ZONE

SCAN HERE

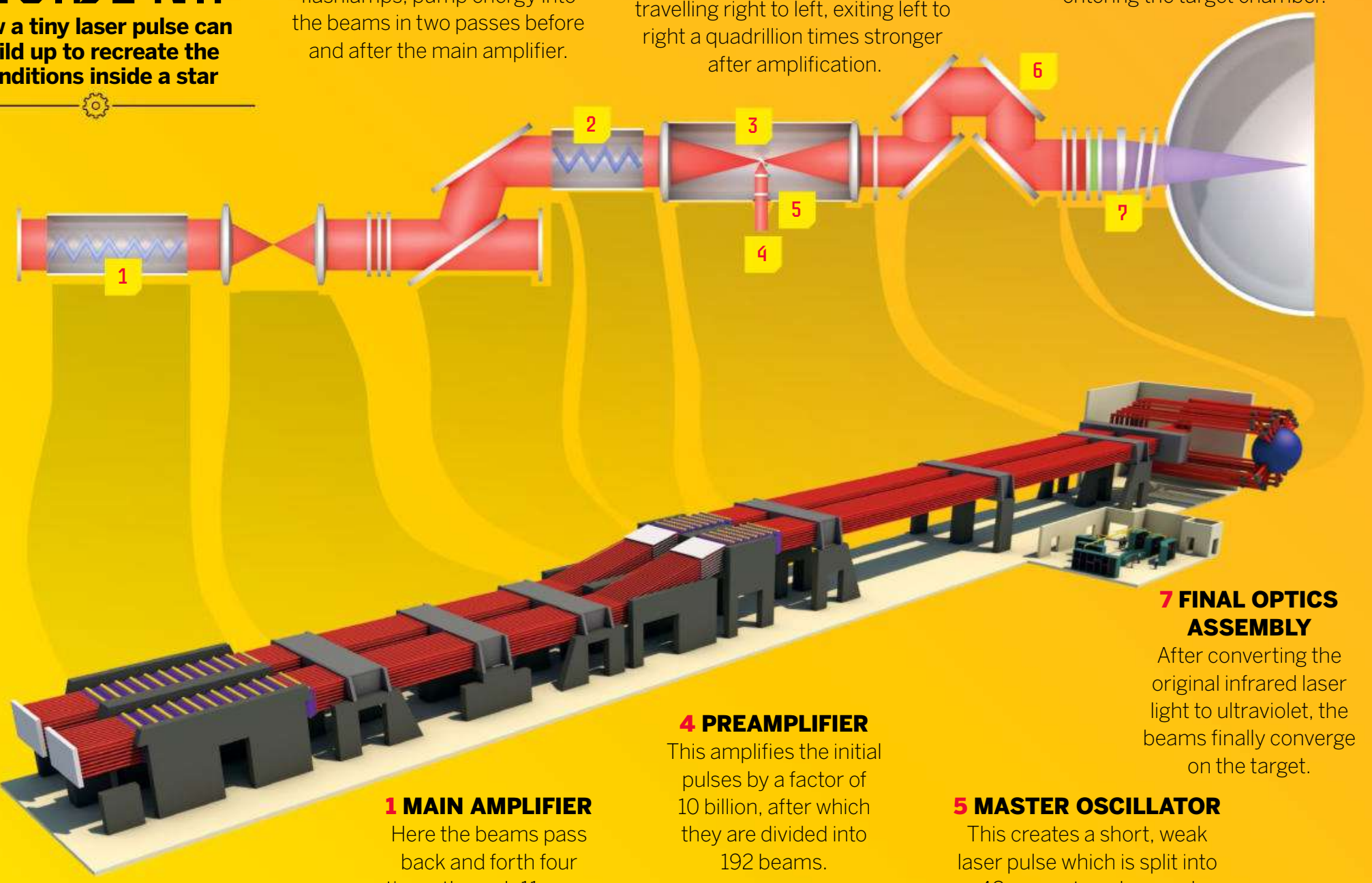
## INSIDE NIF

**How a tiny laser pulse can build up to recreate the conditions inside a star**

**2 POWER AMPLIFIER**
Five glass slabs, surrounded by flashlamps, pump energy into the beams in two passes before and after the main amplifier.

**3 TRANSPORT SPATIAL FILTER**
The original beams enter here, travelling right to left, exiting left to right a quadrillion times stronger after amplification.

**6 TRANSPORT OPTICS**
A series of mirrors rearrange the beams into conical configurations prior to entering the target chamber.




**7 FINAL OPTICS ASSEMBLY**
After converting the original infrared laser light to ultraviolet, the beams finally converge on the target.

**4 PREAMPLIFIER**
This amplifies the initial pulses by a factor of 10 billion, after which they are divided into 192 beams.

**5 MASTER OSCILLATOR**
This creates a short, weak laser pulse which is split into 48 separate pulses and passed to the laser bays.

**1 MAIN AMPLIFIER**
Here the beams pass back and forth four times through 11 more amplifying slabs.

The huge spherical target chamber seen prior to installation in June 1999

The NIF control room resembles NASA's Mission Control, on which it was intentionally modelled

NIF's target is tiny

**DID YOU KNOW?** NIF generated over 10 quadrillion watts of fusion power in one test

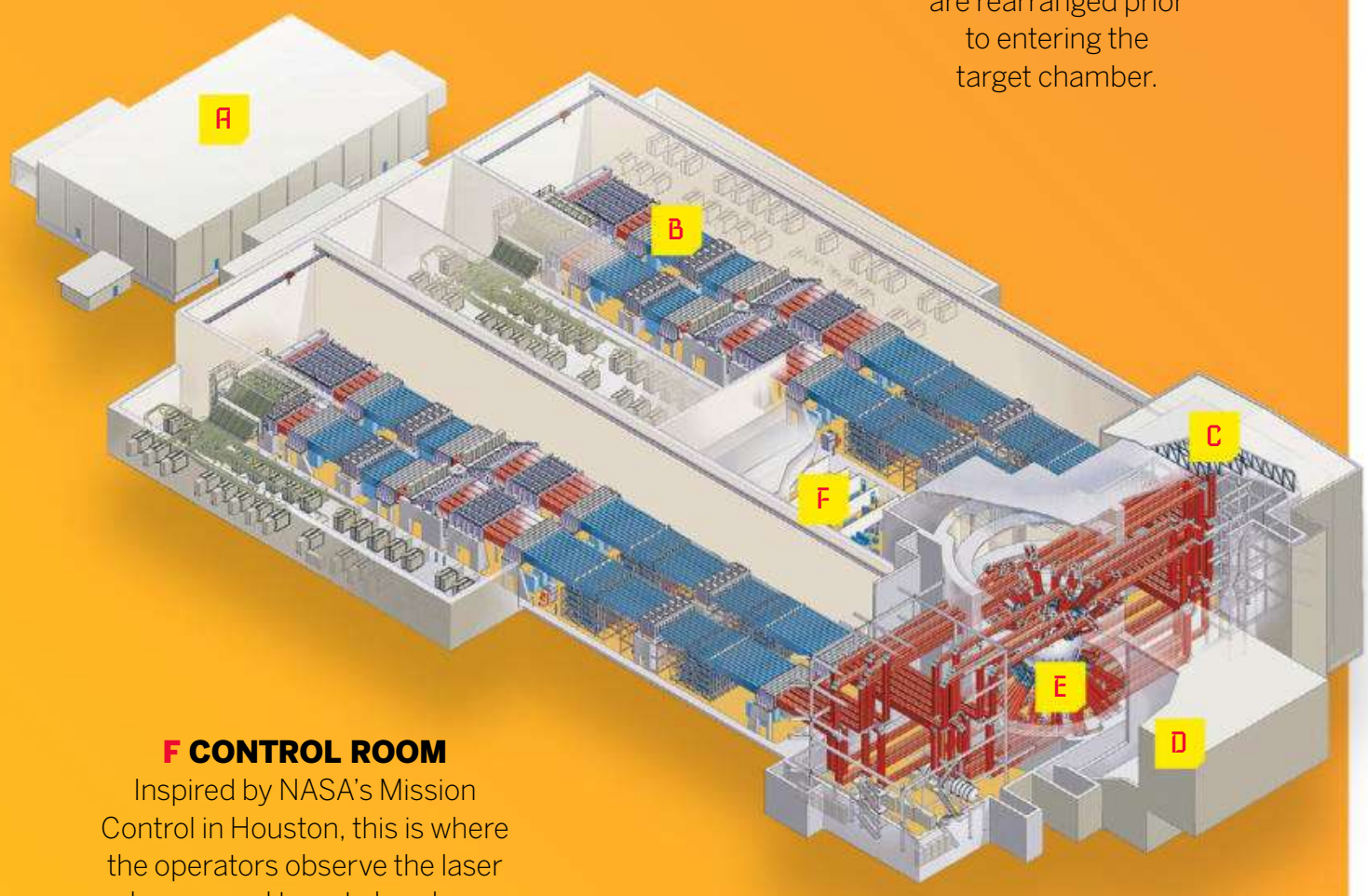
# A HUGE FACILITY

**The National Ignition Facility is the size of a sports stadium, though much more high-tech**

**A OPTICS ASSEMBLY BUILDING**
This is where NIF's optical components are assembled and maintained under stringent clean-room conditions.

**B LASER BAYS**
There are two of these, each containing 96 laser beams and their massive amplifiers.

**C SWITCHYARDS**
After passing through the amplification section, the beams are rearranged prior to entering the target chamber.




**F CONTROL ROOM**
Inspired by NASA's Mission Control in Houston, this is where the operators observe the laser beams and target chamber.

**E TARGET CHAMBER**
This is a sphere ten meters in diameter, made from aluminium ten centimetres thick and encased in 30 centimetres of concrete.

**D DIAGNOSTIC BUILDING**
This contains the highly specialised instruments used by scientists to analyse the results of experiments.

Unfortunately, this has proven to be an elusive goal thus far, and the only fusion reactions that have found a practical use to date are the violently destructive ones that power thermonuclear weapons.

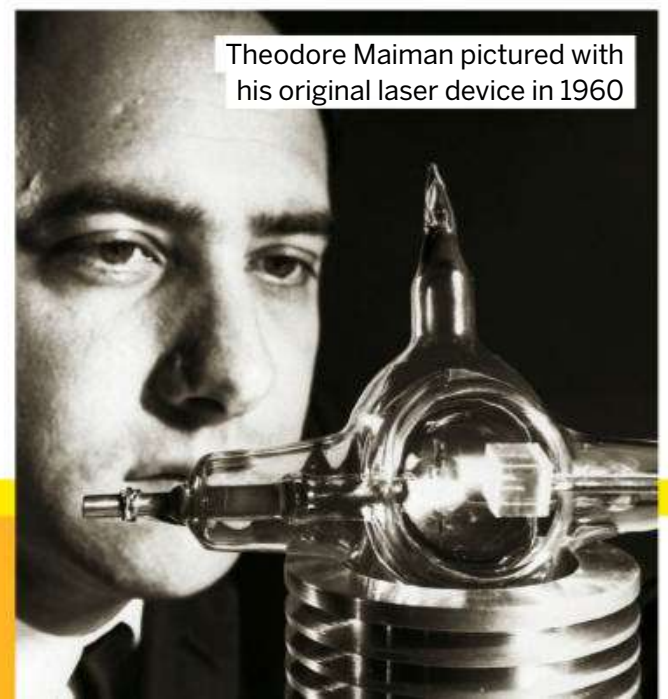
It was in this context that NIF was originally set up. The primary purpose of LLNL is to ensure the safety, security and reliability of America's nuclear deterrent. At one time this involved the active development and testing of new weapons, but thankfully this is no longer the case. LLNL now seeks to maintain the integrity of existing weapons without full-scale testing, and NIF plays a crucial role in this. It's uniquely capable of creating the enormous temperatures and pressures that scientists need in order to study the conditions inside a detonating nuclear weapon.

While weapon-related research still accounts for the bulk of NIF's activities, around eight per cent of its time each year is set aside for more peaceful experiments . These include studies of nuclear fusion in the Sun and other stars, as well as exploring technologies that could facilitate the use of fusion as a future power source on Earth.

But not all of NIF's experiments are related to fusion. Because the laser creates such extreme conditions in terms of temperature and pressure, it can be used to study other situations where these conditions occur, such as the expanding shock waves around supernova explosions or the incredibly dense cores of giant planets, like Jupiter and Saturn.

## HISTORY OF LASERS

**While studying the quantum theory of radiation in 1916, Albert Einstein discovered a phenomenon he called 'stimulated emission'. When a photon of light passes through a material that has excess energy, many more photons can be created that travel in exactly the same direction with the same wavelength. Incredible as it seems in hindsight, no one at the time recognised the enormous practical applications of this. It was only in 1960 that Theodore Maiman constructed the world's first laser. The name stands for 'light amplification by stimulated emission of radiation', which is a perfect description of what it does. Six decades later, lasers are ubiquitous in the modern world, used in everything from DVD players and cat toys to laser eye surgery.**


Theodore Maiman pictured with his original laser device in 1960

© Getty / LLNL / Illustration by Adrian Mann

# FUSION AND FISSION

**Nuclear fusion is different from the fission reactions used in nuclear power stations**

**HEAVY NUCLEUS**
A fission reaction involves splitting the nucleus of a heavy element such as uranium.

**TWO SMALLER NUCLEI**
The unstable nucleus breaks up into two smaller, more stable pieces.

**DEUTERIUM NUCLEUS**
This is a rare but stable variant of hydrogen which contains a neutron as well as a proton.

**FREE NEUTRON**
A fast-moving neutron hits the nucleus and is absorbed into it, making it violently unstable.

FISSION

**NUCLEAR FISSION**
This produces intense radiation as well as further neutrons, causing a chain reaction.

**TRITIUM NUCLEUS**
This is a less stable version of hydrogen with two neutrons.

FUSION

**NUCLEAR FUSION**
The deuterium and tritium combine to form a helium nucleus and a free neutron.

**Did you know?**
America's last nuclear weapons test was in 1992

# IN THE TARGET ZONE

**Just millimetres in size, the target capsule is like a tiny piece of the Sun**

**LASER BEAMS**
The two sets of laser beams converge on the hohlraum and enter through holes in either end.

**HOHLRAUM**
This is a small metal cylinder inside which the nuclear reaction takes place.

**TARGET CAPSULE**
The deuterium-tritium fuel for the reaction is contained inside a plastic capsule.

**NUCLEAR REACTION**
The laser beams heat and compress the target to the point where nuclear fusion can occur.

**DID YOU KNOW?** Every time the laser fires, it generates 800 channels of diagnostic data for scientists to analyse

# USING A GIANT LASER

Despite the laser's enormous size, all the real action takes place inside a tiny metal cylinder called a hohlraum, which is the German word for 'cavity'. But this particular cavity is specially designed to contain a nuclear fusion reaction. The hohlraums used in NIF are less than a centimetre in length and half a centimetre in diameter; they house a millimetre-scale target pellet made from a mixture of tritium, deuterium and ordinary hydrogen. When the hohlraum is flooded with high-intensity laser light, the target pellet absorbs all that energy and a sudden burst of nuclear fusion ensues.

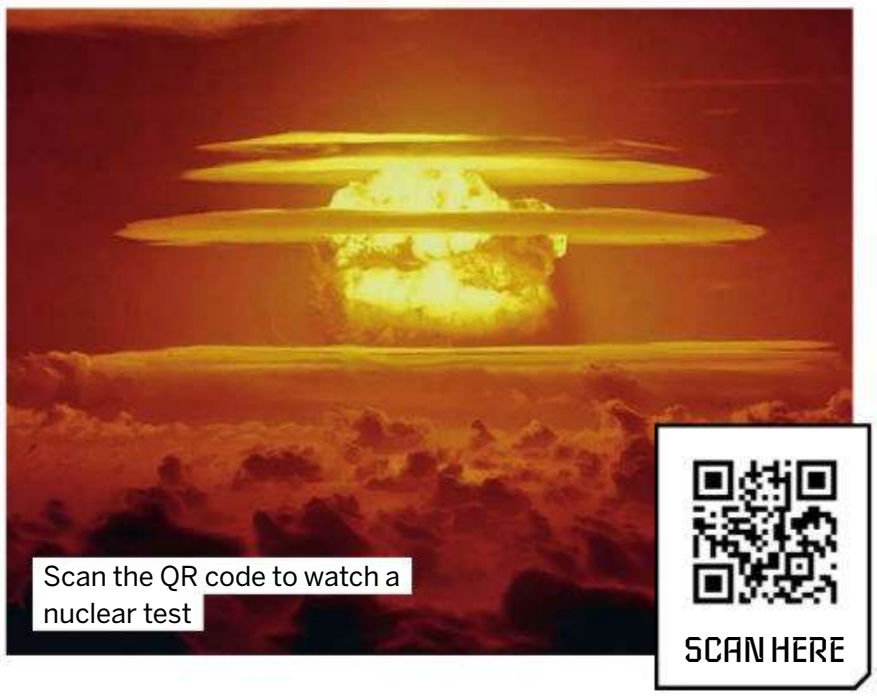
At first glance this may seem something of an anticlimax. Why go to all the trouble of building the world's biggest, most powerful laser for such a specialised task? The answer lies in the fact that fusion reactions are critical to the performance of nuclear weapons, which the US relies on as its ultimate line of defence. In the early days, the only way to do fusion research was to carry out test explosions, which were highly damaging to the environment due to the hazardous radiation they produced. Facilities like NIF provide a much safer, cleaner way to carry out the same kind of research.

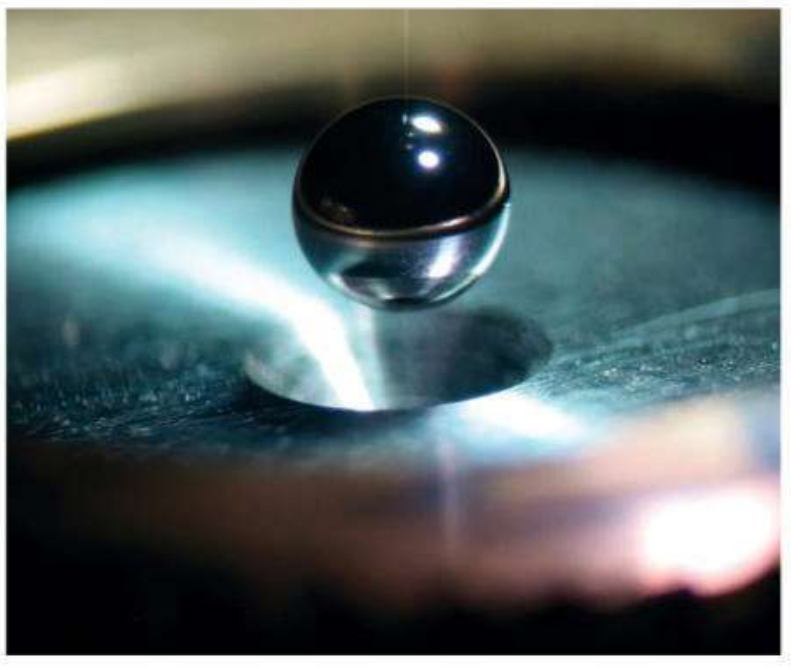
But that's not the only thing that NIF is used for. Around eight per cent of its time is set aside for other activities, including hosting experiments by dozens of partner organisations across America and the rest of the world. Britain's own Atomic Weapons Establishment (AWE), for example, has carried out NIF experiments in order to validate its computer models. Looking beyond weapons research, the facility is also used to study other processes that involve nuclear fusion, including various fields of astrophysics as well as the potential future role of fusion as a sustainable, carbon-free method of power generation.

**Below:** A NIF experiment cosponsored by the UK's AWE to validate computer codes and models

**Bottom left:** NIF can do research that previously required nuclear explosions. Scan the QR code to watch one such test

**Bottom right:** A typical NIF target is a hydrogen-filled sphere made of plastic, beryllium or even diamond



## NIF SCIENCE

**1 NUCLEAR HARDENING**
In addition to the human toll, nuclear explosions can devastate electronic systems, including those controlling defensive weapons. One of NIF's goals is to improve electronic survivability.

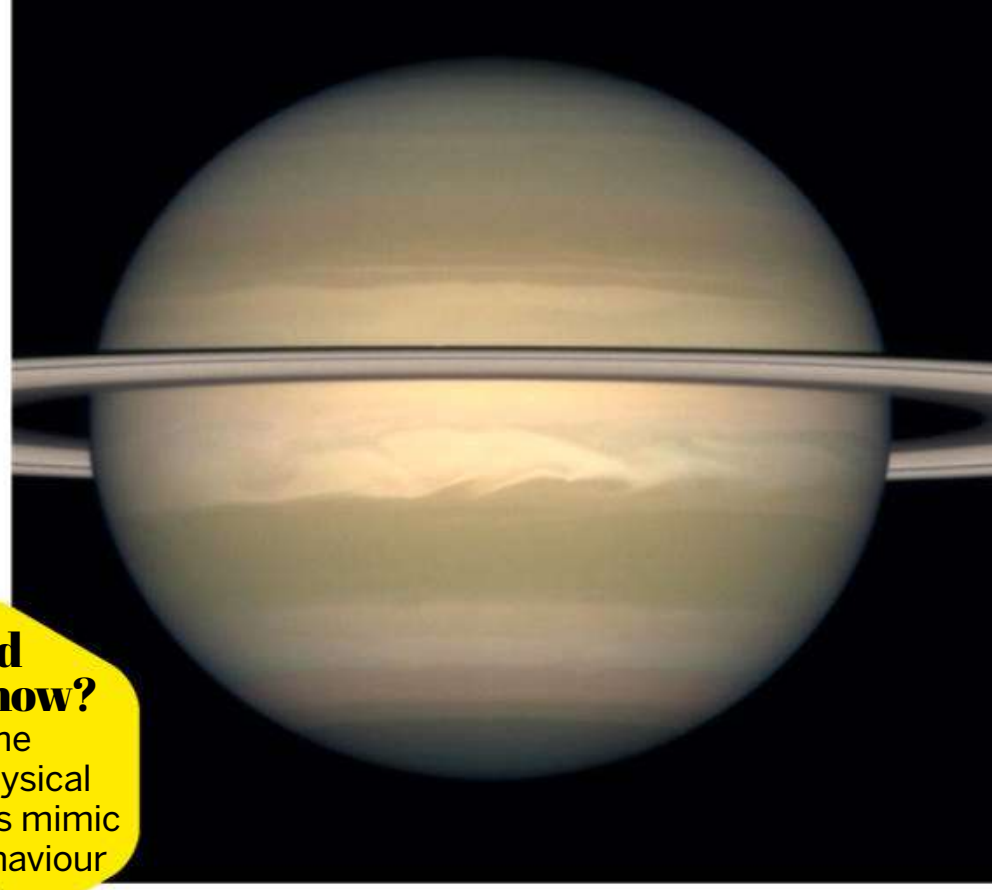
**2 HIGH-DENSITY MATERIALS**
A NIF experiment called Target Diffraction In-Situ – or TARDIS for short – is designed to study how the structure of materials alters when compressed to abnormally high densities.

**3 FUSION POWER**
Most experimental fusion reactors use a system of magnetic confinement to control the superhot fusion fuel, but NIF is studying an alternative in the form of laser confinement.

**4 ADVANCED LASER TECHNOLOGY**
Another NIF program is studying next-generation laser technologies, including ultrafast solid-state lasers and high-peak-power lasers, with a view to advance basic science and develop new commercial applications.

**5 ANTIMATTER**
In 2018 the NIF laser created an electron and its antimatter equivalent, a positron, out of pure energy. This is in accordance with Einstein's famous equation $E = mc^2$.

© Getty / LLNL



**Did you know?**
Some astrophysical processes mimic laser behaviour

# NIF AND SPACE RESEARCH

While the conditions created inside NIF's target chamber are far beyond anything normally seen on Earth, they're much more typical of certain astrophysical environments. This makes NIF an invaluable tool for space research. The interior of a star, for example, undergoes fusion in much the same way – but on a far larger scale – as the nuclear explosions NIF was designed to emulate. In 2017, as part of LLNL's 'Discovery Science' program, it was used to create conditions resembling a stellar interior, allowing researchers to collect data that would be impossible to obtain by any other means.

NIF has also been used to study the physics of supernova shock waves and the ubiquity of cosmic magnetic fields. Thanks to a series of NIF experiments, the latter can now be explained in terms of a phenomenon called the 'turbulent dynamo' effect. In the everyday world, a dynamo is a device for converting mechanical energy into an electromagnetic form, and the NIF experiments suggest that an analogous process in the early universe was responsible for boosting initially weak magnetic fields into the powerful ones that now permeate galaxies.

Another use the giant laser can be put to is compressing material to extremely high densities – much higher than anything found here on Earth, but comparable to the conditions at the centres of giant planets such as Jupiter and Saturn. It's been used, for example, to study the way in which hydrogen turns into a metal under such conditions. And in 2014, NIF was used to squeeze a diamond crystal to a pressure equivalent to that at the centre of Saturn – 14 times the pressure in Earth's own core. A particular challenge in this experiment was to avoid creating enormously high temperatures. While these are desirable in fusion experiments, they're unrealistic in the context of a planetary core. With careful design and planning, however, the experiment succeeded in compressing the diamond to a density similar to that of lead, providing a wealth of data for planetary scientists in the process.

It's conceivable that NIF may have practical space applications of a completely different kind. This is because fusion power, in addition to its potential applications here on Earth, might also be a viable option for spacecraft propulsion. Over the years a number of possible designs have been put forward, but most of these produce fusion reactions in a completely different way from NIF. In 2005, however, LLNL scientist Charles Orth worked with NASA to develop a space propulsion concept based on the same principles as NIF. Called VISTA, for 'Vehicle for Interplanetary Transport Applications', the design employs a conical arrangement of laser beams to initiate fusion in a series of small fuel pellets, with the resulting thrust then being deflected in the desired direction with the aid of powerful magnets.

**Above right:** NIF can reproduce conditions similar to those found in Saturn's core

**Above left:** The immense heat and light of the Sun are the result of nuclear fusion reactions

**"NIF may have practical space applications of a completely different kind"**

## CREATING A TINY SUPERNOVA

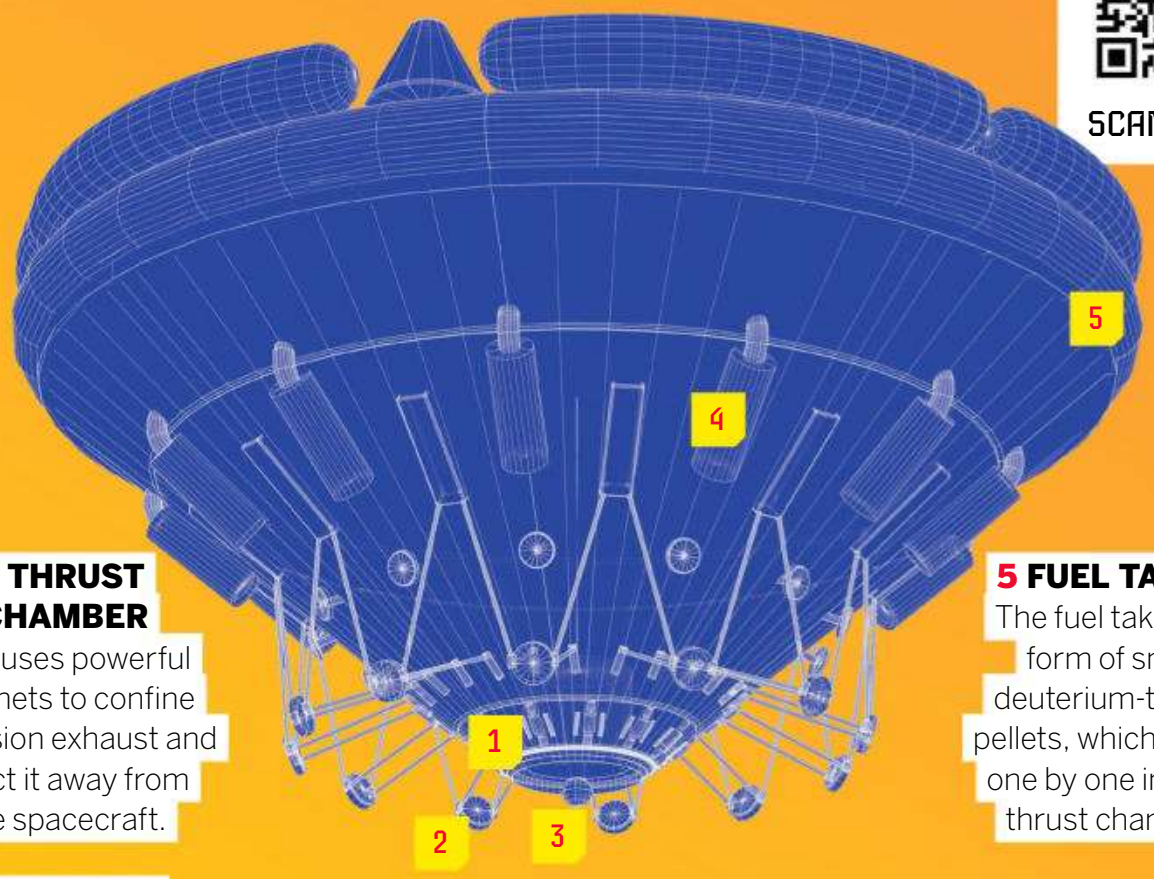
**Supernovae are enormous explosions that occur when large stars run out of nuclear fuel. They're not fully understood because nearby supernovae are so rare. Scientists were mystified as to how supernova shock waves are able to accelerate cosmic rays almost to the speed of light. Thanks to NIF, however, the puzzle has been solved. In 2020, researchers used the giant laser to recreate supernova-like conditions on a miniature scale, finding that turbulence in the shock waves is responsible for the anomalous acceleration.**

Supernovae produce rapidly expanding clouds of gas

**DID YOU KNOW?** VISTA's designers say it could carry a crewed mission to Mars and back in less than four months

# THE VISTA CONCEPT

**LLNL and NASA developed this concept for a fusion-powered spacecraft using NIF-like lasers**



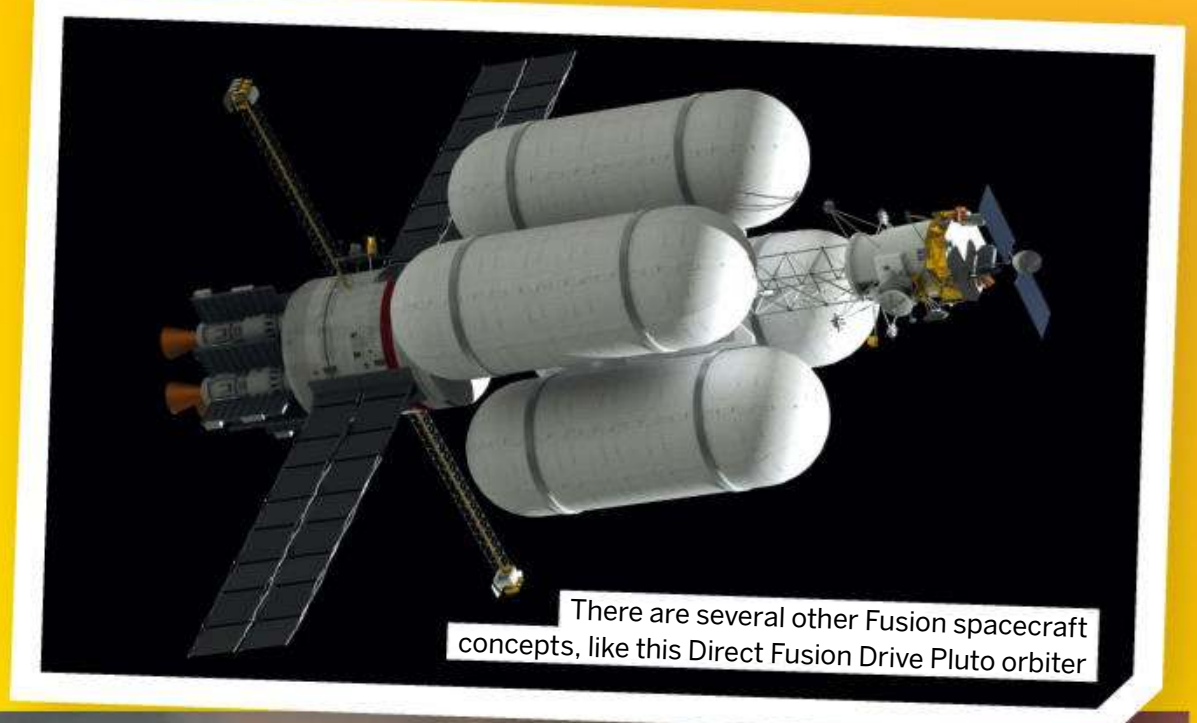

**1 THRUST CHAMBER**
This uses powerful magnets to confine the fusion exhaust and direct it away from the spacecraft.

**2 MIRRORS**
Mirrors focus the laser beams onto the fuel pellet as it emerges from the thrust chamber.

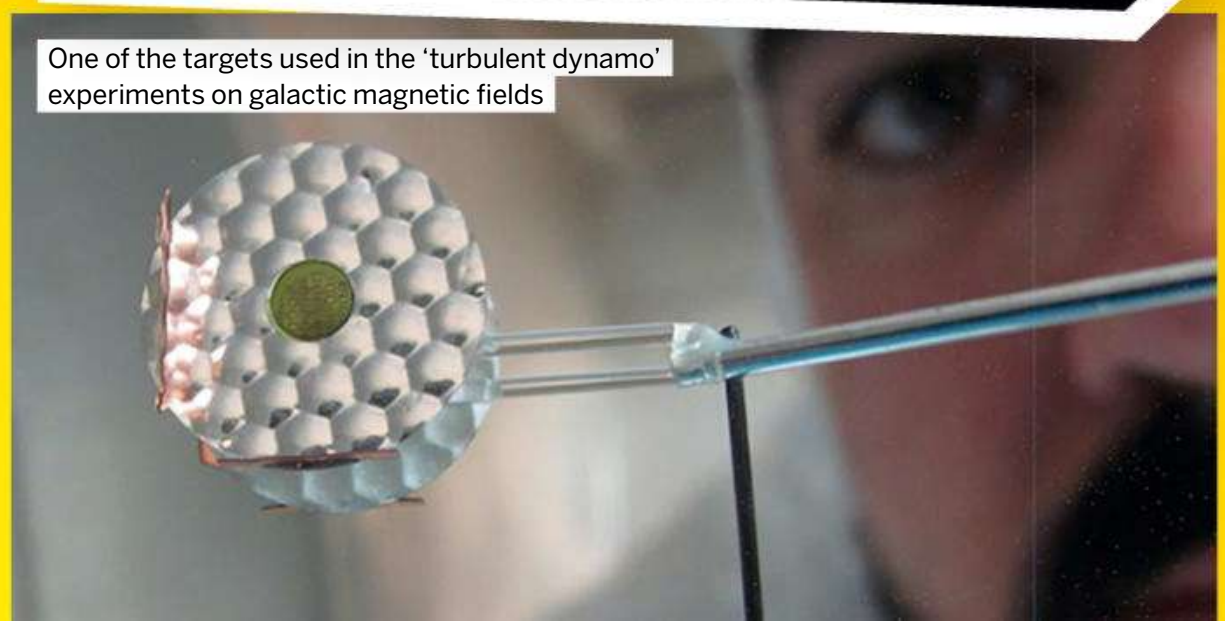
**3 FUEL PELLET**
When this undergoes fusion, the resulting exhaust gases propel the spacecraft in the desired direction.

**4 LASERS**
A conical array of lasers produces the energy needed to ignite the fuel.

**5 FUEL TANKS**
The fuel takes the form of small deuterium-tritium pellets, which are fed one by one into the thrust chamber.



There are several other Fusion spacecraft concepts, like this Direct Fusion Drive Pluto orbiter



One of the targets used in the 'turbulent dynamo' experiments on galactic magnetic fields

AR zone

SCAN HERE

# NIF IN SPACE EXPERIMENTS

**We speak to Jena Meinecke, who used the laser to study cosmic magnetic fields**

Meinecke was based at Christ Church College, Oxford University, when she used the NIF laser

**What did you use the laser for?**

Fast-moving shock waves may be the birthplace of the ubiquitous magnetic fields that pervade our universe. The strength of these fields increases until a unique phenomenon occurs called turbulent dynamo. This is a regime of nonlinear magnetic field amplification commonly observed in the universe, but only recently created here on Earth by our team. We used 255 kilojoules of blue light to generate two highly turbulent, interpenetrating shock waves to stimulate a turbulent dynamo. In doing so, we hope to understand the dynamics of a variety of astrophysical environments, including galaxy clusters and supernovae.

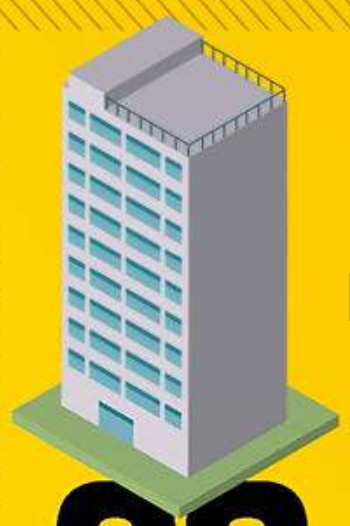
**What are the benefits of this kind of experimental approach?**

The beauty of laboratory experiments is that we can control the conditions of these scaled astrophysical events and monitor them from start to finish. Computer simulations have advanced greatly over the years and can even help predict plasma conditions obtained at many laser facilities. The NIF laser, however, is its own beast. Since it can deliver up to megajoules of energy, the possibilities at the facility are beyond imagination. That being said, we are now entering a phase in which computer simulations are learning from experiments conducted at NIF.

**What's the atmosphere like during a NIF shot? Is it as exciting as it looks?**

I was so overwhelmed by the sheer size of the NIF laser that I nearly fainted on my first visit. Standing next to it is like standing next to Niagara Falls – you feel paralysed by the tremendous power of this machine that towers above you. Running an experiment at NIF is not like running an experiment at any other laser facility. The conditions obtained are so extreme that, to some extent, you have no idea what to expect. All you know is that something special is about to happen.

© Getty / NASA / LLNL / Illustration by Adrian Mann



**30 METRES**

The NIF target bay is taller than a nine-storey building

# 1972

First laser-triggered fusion experiment at LLNL

**$3.5 billion**

Total cost of developing and building NIF – more than NASA's Curiosity mission

**LLNL is named after Ernest Lawrence, inventor of the cyclotron**

# 13.5 MILLION

The number of lines of computer code controlling the laser

**>1**

Ratio of output to input energy needed for practical fusion

# 1920

The year Arthur Eddington suggested the Sun is powered by fusion

**3 NEW CHEMICAL ELEMENTS DISCOVERED AT LLNL**

**NIF's hohlraums are made from gold or depleted uranium**

**The NIF building is the largest clean room in America**

BIG LASE NUM

**DID YOU KNOW?** The Extreme Light Infrastructure, a laser being built in Romania, will be even more powerful than NIF

# LLNL's Project Excalibur was a cancelled space-laser weapon

**1,500 metres**
Total distance travelled by NIF's laser beams

**Lasers play a key role in detecting gravitational waves**

**The 2018 Nobel Prize was awarded for groundbreaking laser inventions**

**1952**
This year saw the test explosion of the first fusion-powered nuclear bomb

**6 metres**
The physical length of laser pulse is as long as three tall humans

**18,000**
The number of parameters needed to define a NIF experiment

**The neodymium in laser glass gives it a pinkish colour**

**The first widespread use of lasers was in barcode readers**

**30 TRILLIONTHS OF A SECOND**
The allowable error in beam timing is over 3 billion times quicker than you can blink

# SEEING SOUNDS AND SMELLING COLOURS

## How does synesthesia combine the senses?

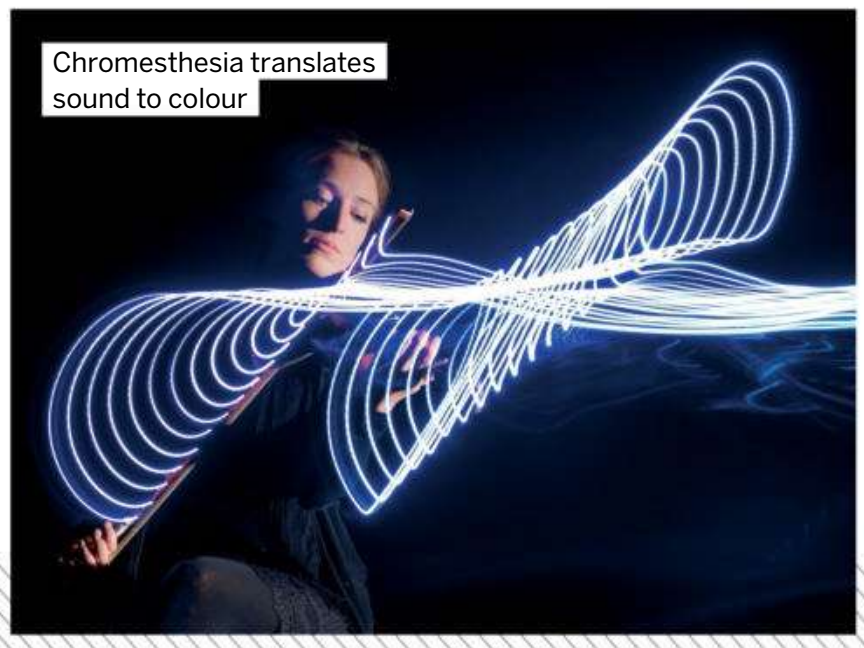
WORDS **AILSA HARVEY**

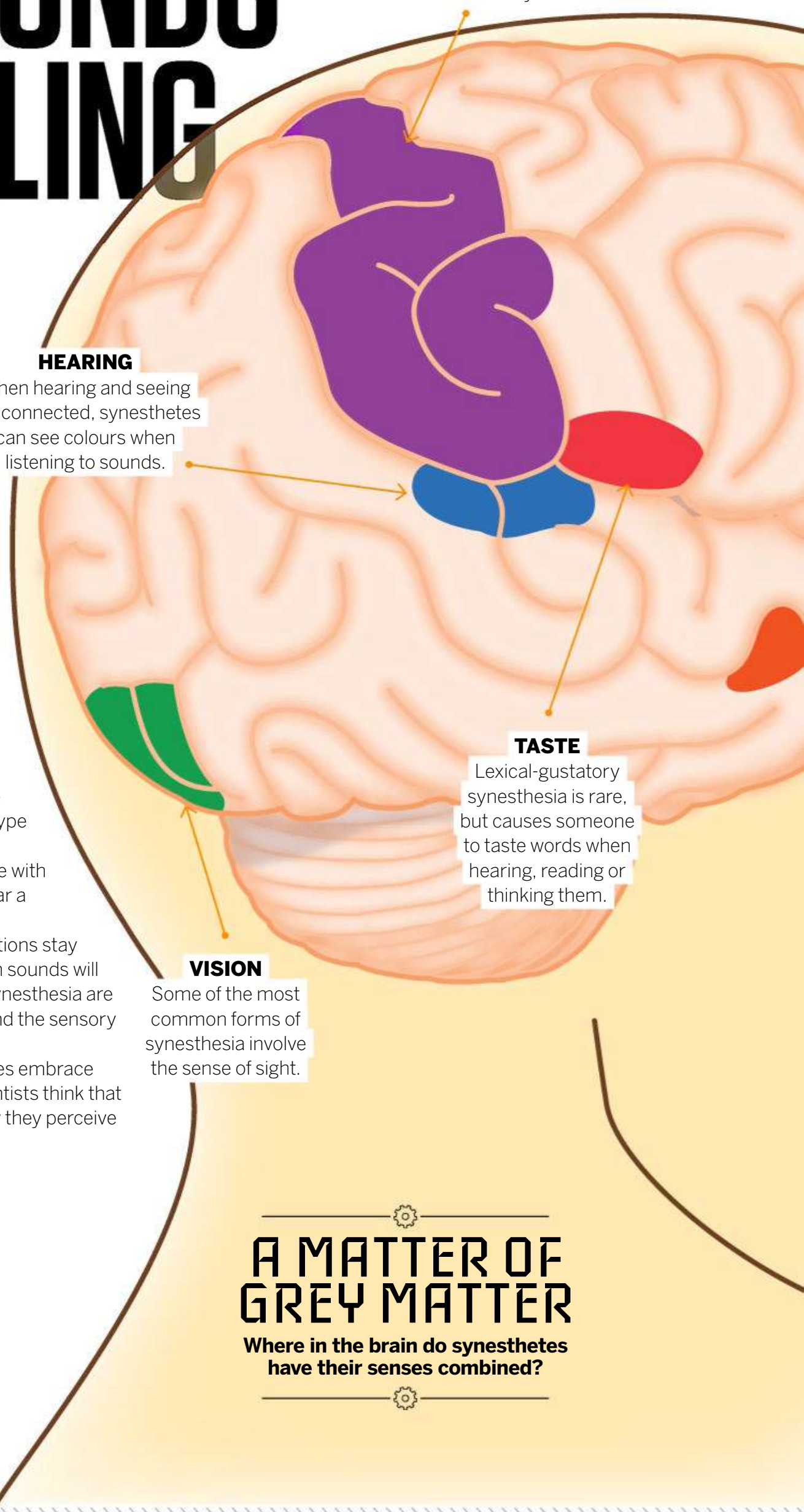
Our senses help us perceive and interact with our environment, whether that's observing colour through sight or using the surface of our skin to feel the shape and texture of objects through touch. The human brain categorises these senses in different areas, but for a minority of people, they can become intertwined. Synesthesia is a neurological condition that can present itself in many forms. People with this condition – referred to as synesthetes – experience the stimulation of several senses from information transmitted from sensory organs that usually activate just one.

The sensory cues that are affected differ among those with the condition, with over 30 variations of synesthesia recorded. One type is chromesthesia, which causes an individual to see shapes of different colours when listening to sounds. For example, someone with this form of synesthesia might see a green triangle when they hear a violin playing, or associate different notes with various colours.

Research suggests that in the majority of cases, these associations stay the same over time. The green triangle that appears when a violin sounds will continue to represent this sound many years later. People with synesthesia are usually born with it or develop the condition early in childhood, and the sensory associations become more predictable over time.

There is no treatment for synesthesia. In fact, many synesthetes embrace their differences, seeing it as an enhancement to their lives. Scientists think that synesthesia can go unnoticed, as each individual only knows how they perceive the world, and may assume that to be 'normal'.

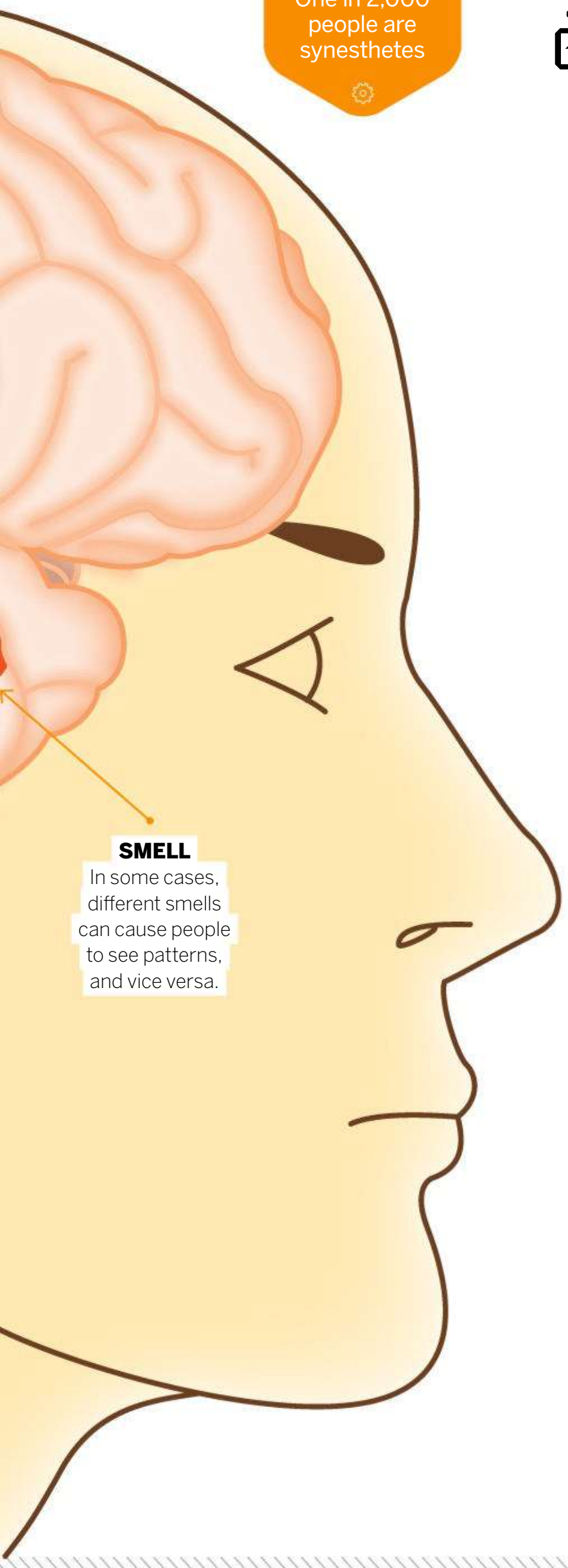

Chromesthesia translates sound to colour


TOUCH
Mirror-touch synesthetes feel the sensation of being touched on the opposite side of their body.
HEARING
When hearing and seeing are connected, synesthetes can see colours when listening to sounds.
TASTE
Lexical-gustatory synesthesia is rare, but causes someone to taste words when hearing, reading or thinking them.
VISION
Some of the most common forms of synesthesia involve the sense of sight.

### A MATTER OF GREY MATTER

**Where in the brain do synesthetes have their senses combined?**

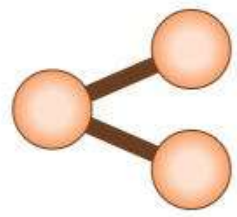
**Did you know?**
One in 2,000 people are synesthetes



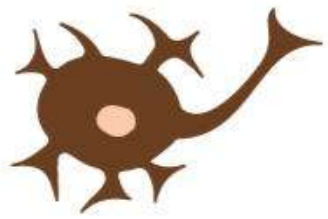
**SMELL**
In some cases, different smells can cause people to see patterns, and vice versa.

# HOW YOUR SENSES CAN GET MIXED UP

**PERCEPTION**
The brain’s grey matter holds most of the neuronal cell bodies and is responsible for sensory perception.



**BRAIN AT BIRTH**
At birth, neural connections in the brain can overlap. In some cases these remain connected.



**NEURONAL PRUNING**
By the age of four months, the areas of the brain that perceive vision, hearing and other senses separate.

**MULTIPLE SENSES**
When two of these regions of the brain are still connected to each other, a multisensory experience can take place.

**CROSS-ACTIVATION**
One theory for the cause of synesthesia is that neuronal pruning isn’t fully completed. This may be hereditary.

Some people with synesthesia see different letters in different colours

## STUDYING SYNESTHESIA

**In 1812, George Sachs wrote the first scientific report on synesthesia. This work was based on his own sensory experiences. However, at this time, internal feelings couldn’t be analysed by science, and thus the details of his accounts faced great scepticism.**

**In 1980, neurobiologist Richard Cytowic carried out the first neurophysiological studies on people with synesthesia. Cytowic is credited with returning the topic of synesthesia to science and sparking more research into understanding the condition.**

**Modern technology means that brain activity can be studied through an electroencephalogram (EEG). Sensors are attached to the head to detect the strength of electrical signals in the brain. By monitoring which areas of the brain are stimulated when exposed to different sensory cues, scientists can determine which neural connections may be linked in an individual.**

An EEG can detect abnormalities in brain waves

© Getty

# GOLD: THE RICH ELEMENT

## How this versatile, unique metal forms, and how it's extracted and used today

WORDS JAMES HORTON

**"Many have died for gold, and many have killed for it"**

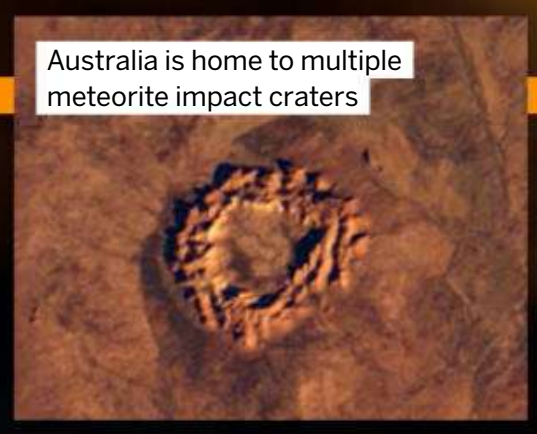
Gold represents a tiny fraction of the elements in the known universe. The reason for its rarity is owed to the incomprehensible amount of energy needed for its formation. Gold is formed within stars, but only in those that are exploding in giant supernovae or incredibly dense ones that have come together in monstrously powerful collisions.

Stars generate energy through the power of fusion, where smaller elements are fused, or combined together into heavier elements. To start with, a star may be mostly hydrogen, the lightest element. The process of fusion under the immense pressure and heat in the star's core will generate helium. When hydrogen runs low and the star begins to reach the next phase of its life cycle, it will fuse helium into the next heavier element, and so on. This process continues until the element iron is made, where the balance suddenly shifts – fusing iron doesn't create energy, it consumes it. With no means of generating internal energy to counteract its own immense pressure and gravity, the star begins to collapse onto itself. If the star is large enough, the result is a supernova – a massive stellar explosion. Heavier elements are formed from the incredible energy generated during this process, including gold.

Very few cosmic events can generate the levels of concentrated energy as within a collapsing aged star, but one that can surpass it is collisions between neutron stars. Neutron stars are small and incredibly dense stars that fell short of becoming black holes. They generate huge gravity and can enter another's orbit. This can result in collisions of enormous magnitudes, generating enough energy to form gold and other heavier metals.

Once flung out into the void of space, gold and other elements slowly came together to form the nexus of our fledgling planet. Over time, as the Earth cooled and separated into layers of core, mantle,and crust, the gold trapped deep within was forced towards the surface. Several theories have been suggested as to how this process occurs, but a shared theme is that heat and pressure forced liquid water up, carrying dissolved gold as it travelled. As the water cooled, the gold precipitated out of solution, forming veins or lodes of concentrated gold.

Over time, some gold travelled through the conduit of water yet further, up to the surface and into rivers. Here small nuggets of gold ran downstream. Perhaps the very first piece was encountered by a fisherman who spied a glint, dipping his hand into the water to recover the chunk of shiny metallic yellow. Thousands of years after this first occurred, gold prospectors and miners would treat gold nuggets in water as a sign of a lode nearby, and they'd busily get to penetrating the ground in search of gold veins to mine. Throughout the history of humanity, many have died for gold, and many have killed for it. But despite that, the story of where gold has taken our species is perhaps not as fascinating as where the element began.



Australia is home to multiple meteorite impact craters

### UNEXPECTED FIND

Gold plays a strong role in Australian history. In the late-19th century, so many flocked to the country to take part in its booming 'gold rush' that the population tripled. Owing to pervasive deposits, it's still mined today. However, one company, Evolution Mining, found a different treasure in its hunt for gold. When drilling into the Australian Outback's surface in search of gold deposits, miners instead unearthed sheets of stone that resembled 'shatter cones', which form on the outer rims of impact craters. They followed up this finding with advanced mapping techniques, confirming the uncovering of a three-mile-wide meteorite crater.

Gold's natural purity and attractive colour have captivated human civilisations for thousands of years

**DID YOU KNOW?** Gold's purity can be measured in karats. 24k gold is entirely pure, but 14k is more common in jewellery

Gold – and other elements heavier than iron – are formed just before stars explode into supernovae



Scientists believe that gold forms following a collision between neutron stars

## Did you know?

Gold 'lookalikes' are known as 'fool's gold'



Egyptian pharaoh Tutankhamun's funerary mask was made of gold, and has endured for thousands of years

## GOLD THROUGHOUT HISTORY

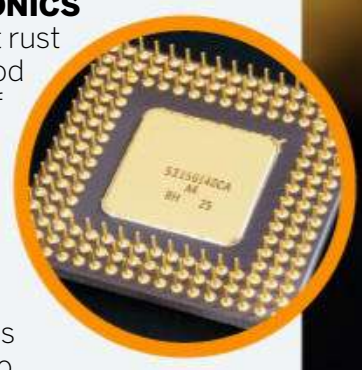
**5,000 years ago, the massive Nile River was the key to the ancient Egyptian empire. Its water allowed a bounty of crops to be grown along its edge, keeping its citizens, and its armies, well fed. But there was also a shiny yellow metal that came running down the river: gold. The ancient Egyptians eagerly took this visually appealing treasure, finding that because it was naturally pure and malleable, it required little refinement to be turned into mesmerising decorations. Gold swiftly came to be a symbol, and unit, of wealth, and it has maintained this allure through time and around the globe. Several millennia after the Egyptian pharaohs and their tombs of gold, the Aztec Empire's golden riches were plundered by the conquistadors, who sought the valuable metal for their own. Later still, workers flocked to the western coast of the United States to take part in the California Gold Rush, seeking their own fortunes.**

## 4 COMMON USES OF GOLD

### 1 MEDALS AND JEWELLERY

Due to its beautiful colour, its rarity and its malleability, allowing it to be folded into all manner of shapes, gold has been a coveted jewellery material for millennia.

### 2 ELECTRONICS



Gold doesn't rust and it's a good conductor of electricity, making it a useful item for modern-day electronics. Gold coatings are applied to connectors both for terrestrial uses and for spacecraft.

### 3 DENTISTRY

As well as being a hard-wearing metal that is pliable and doesn't rust, gold is also non-toxic. This makes it an excellent component of fillings used to fill cavities in dentistry.

### 4 BULLION

A rare metal that is non-toxic and remains untarnished by rust makes for an ideal medium of wealth exchange. Ancient civilisations used gold within their physical currency as coins, but today wealth is primarily invested into gold by purchasing bullion.

© Getty / NASA / Wiki: Christian Tørrissen, Martinvl, Andrew Dunn, PHGCOM

Intravenous treatment is used by many cancer patients

Pills are just as effective as an IV drip

**Did you know?**
After chemo, more targeted treatment is usually used

# WHAT IS CHEMOTHERAPY?

## Discover how powerful drugs can be used to destroy cancer cells

WORDS **ISOBEL WHITCOMB**

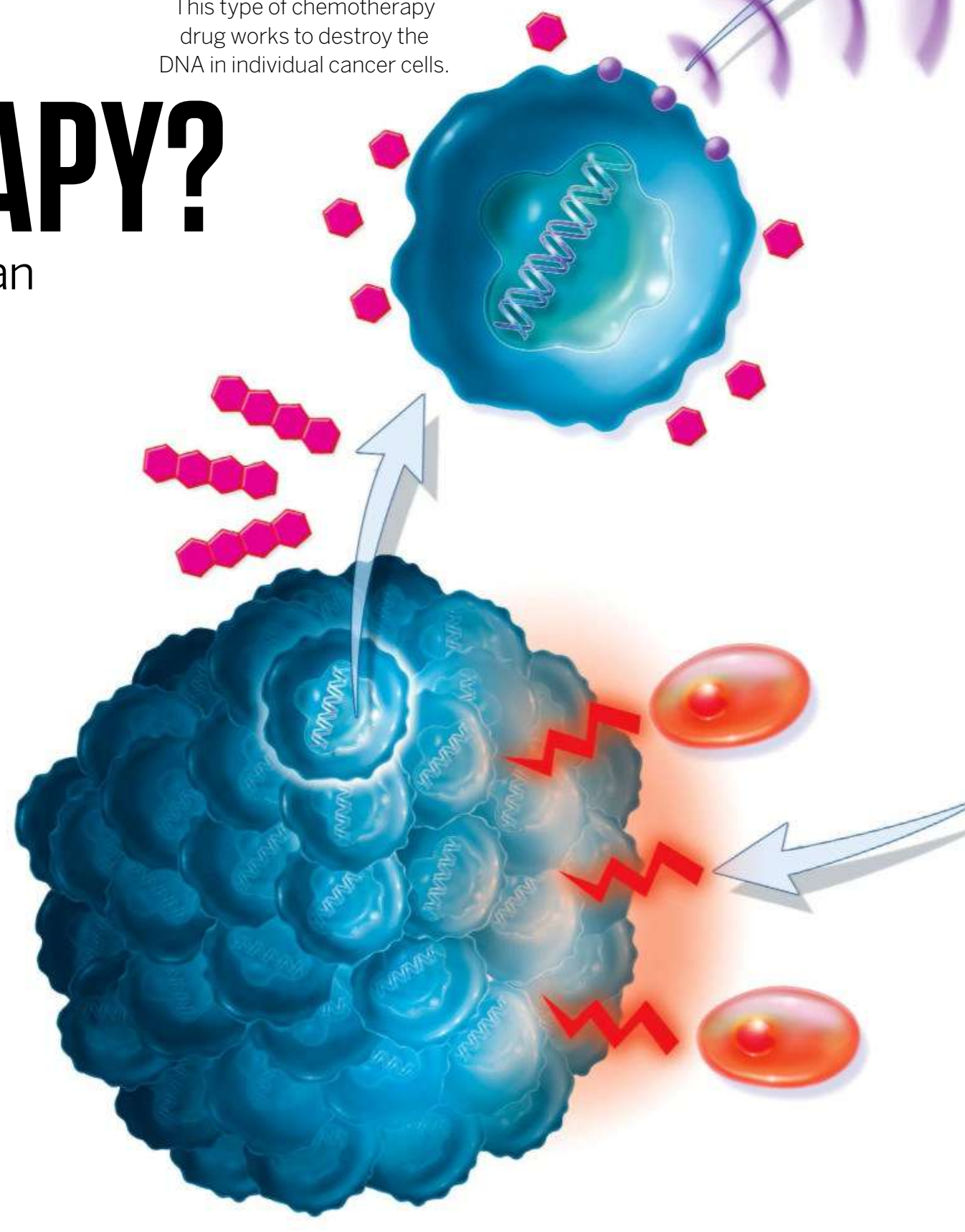
Chemotherapy is a type of cancer treatment that uses chemicals to kill harmful, cancerous cells and prevent them from reproducing. Chemotherapy has become a mainstay for treating rapidly spreading cancers, and combined with other therapies can help force cancer into remission or keep it from spreading further. While chemotherapy is often confused with radiation, these two treatments are very different. Chemotherapy acts on the whole body, while radiation therapy treats specific regions of the body in isolation.

Because chemotherapy acts on the body as a whole, it's particularly effective at treating rapidly spreading cancers. When cancerous cells escape from one region of the body and migrate through the bloodstream, chemotherapy can kill these cells while they're en route to other parts of the body. A more localised treatment, like radiation or other targeted therapies, can easily miss these rogue, travelling cells.

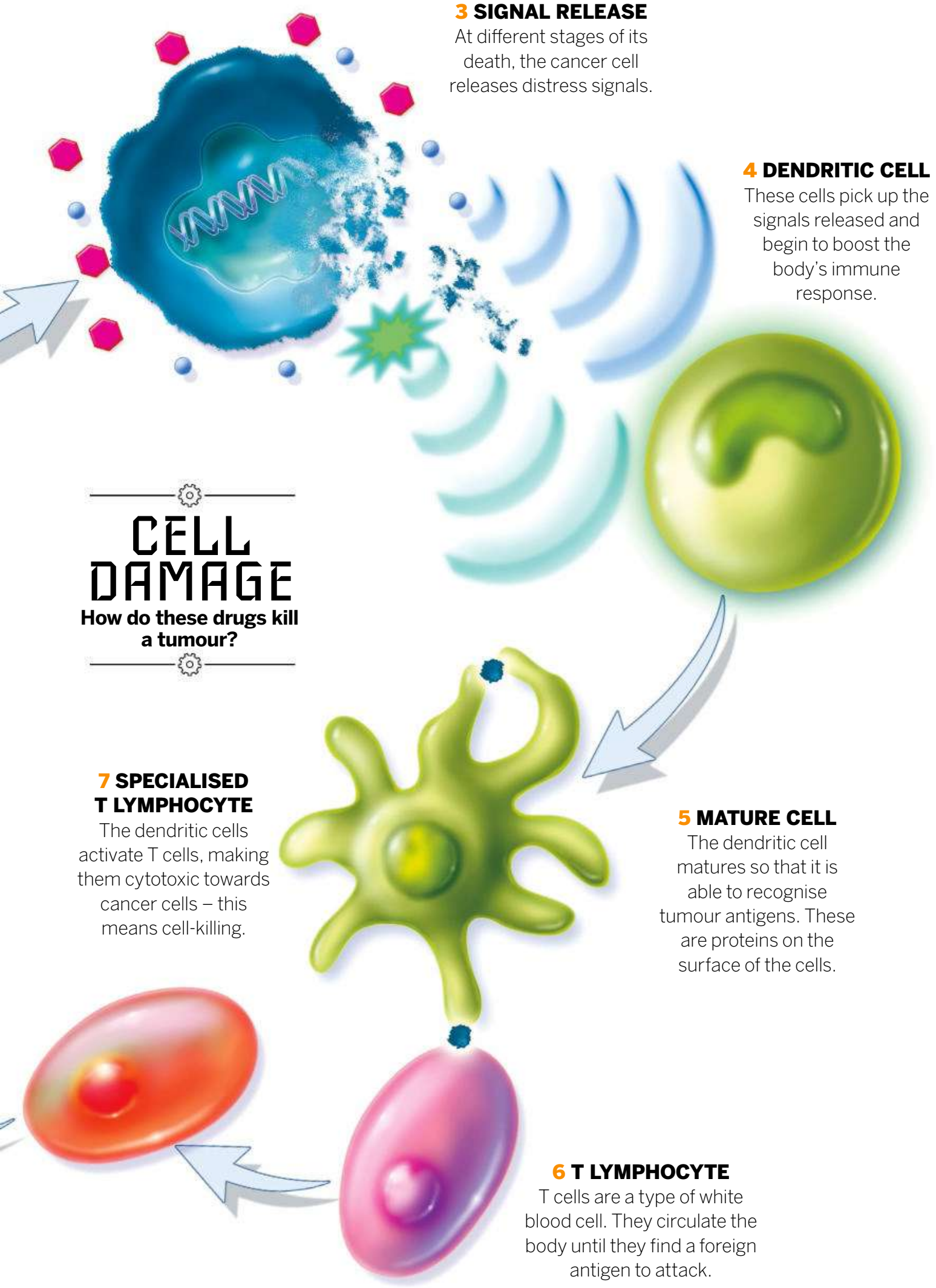
The goal is to get the chemotherapy drug across the entire bloodstream so that if there are any lurking cancer cells, they can be treated before they wreak havoc on the body. Patients prescribed chemotherapy may receive the drug through an intravenous (IV) drip, an injection or orally, either as a pill, capsule or liquid. Chemotherapy drugs include alkylating agents and antitumour antibiotics, both of which work by damaging the DNA of cells to stop the cells from replicating. Other drugs include topoisomerase inhibitors and mitotic inhibitors, which work by interfering with enzymes or proteins that spark the reactions necessary for cell division and reproduction. Which drug a patient is given depends on the type of cancer and its severity.

**1 ANTHRACYCLINE DRUG**
This type of chemotherapy drug works to destroy the DNA in individual cancer cells.

**2 CANCER CELL**
Tumour cells are targeted by chemotherapy drugs because they divide more frequently than other cells.



**DID YOU KNOW?** Chemotherapy drugs can remain in your body for a few hours to a few days



**3 SIGNAL RELEASE**
At different stages of its death, the cancer cell releases distress signals.

**4 DENDRITIC CELL**
These cells pick up the signals released and begin to boost the body's immune response.

## CELL DAMAGE

**How do these drugs kill a tumour?**

**7 SPECIALISED T LYMPHOCYTE**
The dendritic cells activate T cells, making them cytotoxic towards cancer cells – this means cell-killing.

**5 MATURE CELL**
The dendritic cell matures so that it is able to recognise tumour antigens. These are proteins on the surface of the cells.

**6 T LYMPHOCYTE**
T cells are a type of white blood cell. They circulate the body until they find a foreign antigen to attack.

**8 ATTACKING CELLS**
When these cells encounter dividing cancer cells in the body, they will attack and kill them. This limits the spread of cancer around the body and the growth of tumours.

**"It's particularly effective at treating rapidly spreading cancers"**

Around ten per cent of cancer diagnoses in the US are for blood cancer

## TREATMENT DISCOVERY

**In a way, chemotherapy was invented by accident after research into the effects of a chemical weapon. In 1942, Dr Alfred Gilman and Dr Louis Goodman were contracted to come up with an antidote to the toxic effects of mustard gas. Early experiments with rabbits suggested mustard gas was harmful because it killed white blood cells – the main cells of the immune system. Those results led Gilman and Goodman to wonder whether mustard gas could be used to fight a different kind of enemy: blood cancer.**

**Their first human patient was a Polish immigrant with a case of lymphatic cancer. Chemical treatment with mustard gas initially seemed to work. Tumours shrunk and he began to regain energy and mobility. But the treatment's side effects killed him within three months. Since that first treatment, research has led to the development of an array of other chemotherapy drugs that are safer.**

Chemotherapy patients may lose hair all over their bodies

## WHY SOME PEOPLE LOSE THEIR HAIR

**Side effects are common with both oral and IV chemotherapy. Because chemotherapy attacks cells throughout the body, it tends to take down healthy cells along with the cancerous ones. Cells that divide rapidly are especially vulnerable to chemotherapy. In some patients, chemotherapy leads to hair loss as the cells in hair follicles, which normally regenerate every few days, die off. Side effects wear off between weeks and months in most patients.**

© Getty / Alamy / JACOPIN, BSIP, Science Photo Library

# EXTREME DESERT RACING

WORDS **AILSA HARVEY**

**The vehicles and technology behind the Dakar Rally, the toughest cross-country race in the world**

The Bahrain Raid Xtreme, which debuted in the 2021 Dakar Rally

The Dakar Rally is designed for the extreme racer. Facing unpredictable terrain, severe temperatures and fearless speeds, competitors navigate some of the world's most desolate and challenging deserts in what's known as a 'rally raid'. In a range of vehicles, from lightweight motorbikes to sand-pounding mega-trucks, competitors battle it out in a test of physical endurance and unremitting concentration. Competitors need to drive across sand, rock and gravel for thousands of miles as they focus on navigating their sparse surroundings.

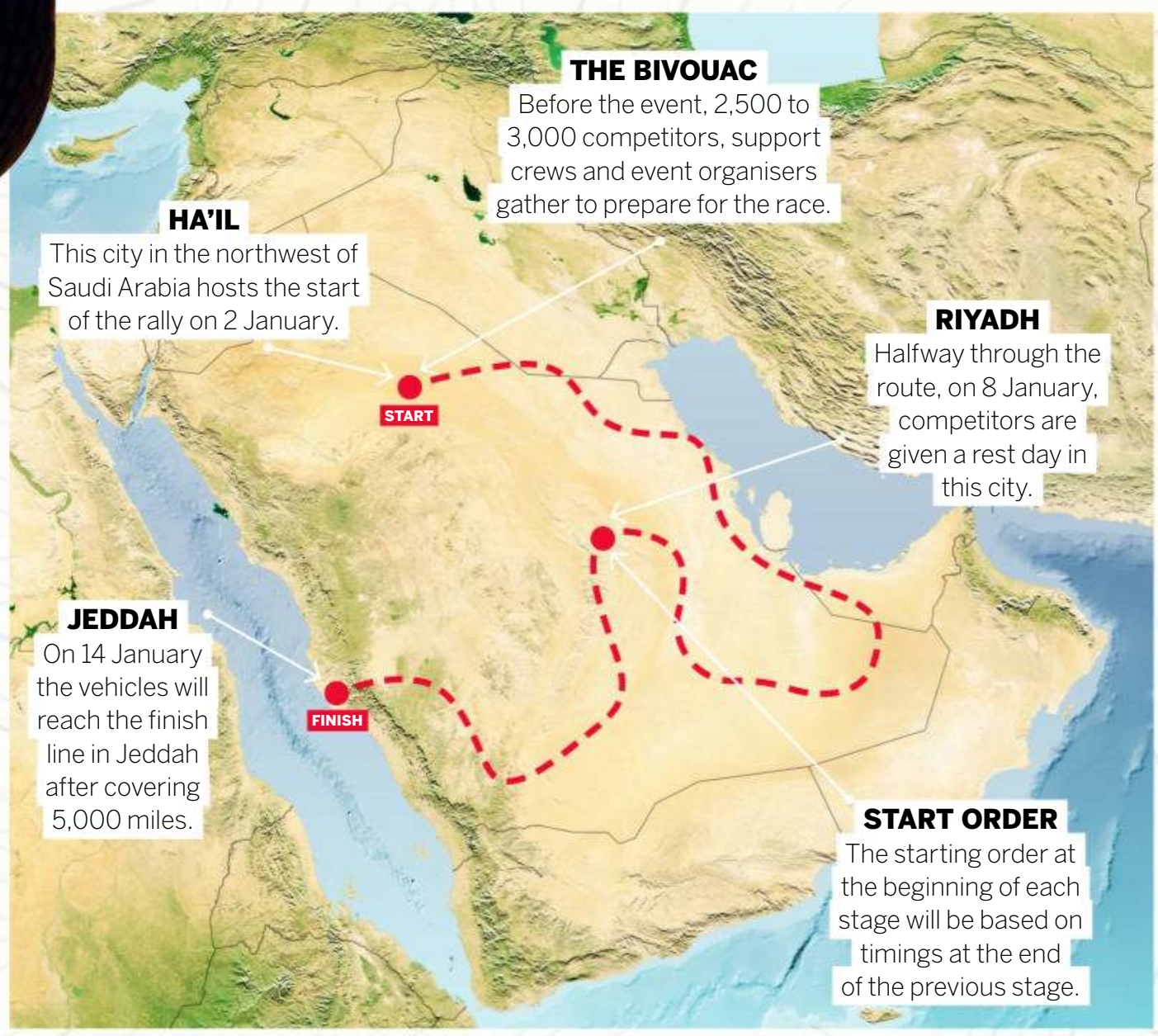
With no chance for a test run, the Dakar Rally requires racers to make their way through each segment using a set of specific instructions that are handed out on the day. Amateur drivers are given a physical copy on a sheet of paper, which they can attach to their vehicles, while the elite competitors can request an electronic copy. In 2022 the rally will take place entirely in the Arabian Desert of Saudi Arabia, the 30th country to host the race since its debut in 1978. There will be one stage per day over the course of nearly two weeks, including a marathon. In this stage, no assistance from support crews is allowed.

**Did you know?**
Racers often colour-code their roadbooks before the rally

The Dakar Rally is classed as the toughest motor race in the world. As well as perfecting their navigational abilities and performing fearless manoeuvres to contend for the podium, rally racers require a keen sense of adventure. After all, the event only began because of the risks one French motorbike rider took when competing in the Abidjan-Nice Rally in 1977: Thierry Sabine became lost in the Libyan Desert and was forced to navigate the sands back to familiar land. He loved the challenge and thrill that this provided so much that one year later he launched the now world-famous Dakar Rally.

## DAKAR 2022 ROUTE

**A broad overview of the course, the exact route is secret until the day of the rally**


THE BIVOUAC
Before the event, 2,500 to 3,000 competitors, support crews and event organisers gather to prepare for the race.
HA'IL
This city in the northwest of Saudi Arabia hosts the start of the rally on 2 January.
START
RIYADH
Halfway through the route, on 8 January, competitors are given a rest day in this city.
JEDDAH
On 14 January the vehicles will reach the finish line in Jeddah after covering 5,000 miles.
FINISH
START ORDER
The starting order at the beginning of each stage will be based on timings at the end of the previous stage.

© Getty

# WHAT MAKES A WINNING RALLY CAR?

## The Volkswagen Race Touareg achieved three consecutive wins at the Dakar Rally

**CARBON-FIBRE MATERIAL**
The car's outer body is made from light carbon fibre. In total the bodywork weighs 50 kilograms.

**AIR INLET**
Air is drawn into the vehicle here to cool the car's internal components.

**ENGINE POWER**
The Touareg has a five-cylinder engine with a 2.5-litre capacity.

**COCKPIT CONDITIONS**
In a relentless rally, it's essential that the driver is comfortable and can change the car's conditions. This includes manually adjustable air conditioning.

**TUBULAR FRAME**
The sturdy frame is made from aircraft steel. The tubular structures provide equal strength from any angle.

**INTERCOOLING SYSTEM**
The intercooler works to lower the temperature of the car's gas, reducing fuel consumption and increasing efficiency.

**SUSPENSION**
Dakar regulations mean that each wheel is limited to 250mm in spring travel.

> "Rally racers require a keen sense of adventure"

**DID YOU KNOW?** Some of the lorries that compete in the Dakar Rally are also support trucks for other vehicles

Crashes at the rally are common, and have claimed over 70 lives

An awards ceremony takes place at the end of the two-week event

**PUNCTURE PREPARATION**
The boot of the car is adapted to hold spare tyres. These are replaced in the event of a puncture.

**OFF-ROAD WHEELS**
The 25-centimetre-wide wheels ensure that a large area of tyre is in contact with the sand, spreading the weight across its surface.

**Did you know?**
The rally was held in Africa for 30 years and South America for 11

AR zone
SCAN HERE

## 5 DAKAR CATEGORIES

**1 MOTORBIKES**
Bikers must have completed a leg of a World Cup or Dakar Series race to compete in the Dakar Rally. Elite riders are given yellow number plates to set them apart.

**2 QUADS**
Quad bikes can be two-wheel drive or four-wheel drive. The maximum engine capacities are 750cc and 900cc respectively.

**3 CARS**
Rally cars are usually designed with a fibreglass or carbon frame. Many are similar to 4x4s that you would find in a dealership, but they are modified to include features such as a roll cage. This sturdy frame protects the driver in the case of the car rolling over.

**4 TRUCKS**
The most common trucks are prototypes, but components such as the cabin must be production-based. Their speeds can reach up to 87 miles per hour.

**5 LIGHTWEIGHT VEHICLES**
These vehicles have fuel tanks of 130 litres or less, giving them a range of 155 miles. Their shorter range means they use the same refuelling stations as motorbikes.

© Alamy / Getty / Illustration by Nicholas Forder

AR ZONE

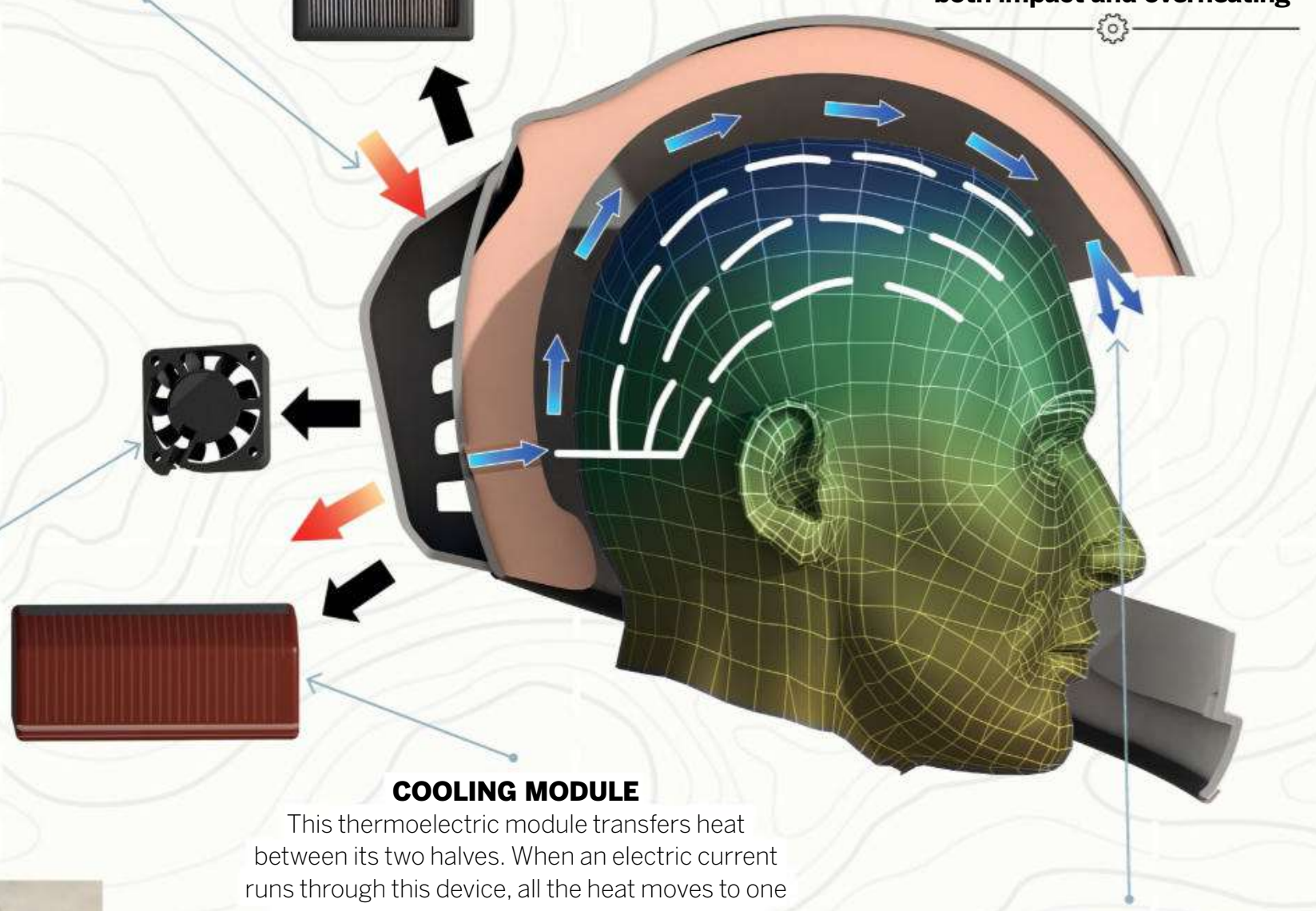
# COOLING WITH SPACE TECHNOLOGY

Controlling the temperature of vehicles and drivers is essential in any off-road endurance event. However, during the Dakar Rally, which famously traverses sweltering desert lands, cooling technology has an increased priority.

In the past, technology used by the European Space Agency (ESA) has been incorporated into the Dakar Rally. One piece of technology used in vehicles is a thermal screen, which was also used in one of the ESA's space launch vehicles. The screen wraps around the exhaust pipe and can cool it by 700 degrees Celsius. In addition to the car's temperature, rally drivers have been known to use self-cooling drink containers and air-conditioned helmets.

## KEEPING A COOL HEAD

**Thermoelectric technology means helmets can protect drivers from both impact and overheating**



**AIR IN**
The air surrounding the helmet is drawn in here to be cooled.

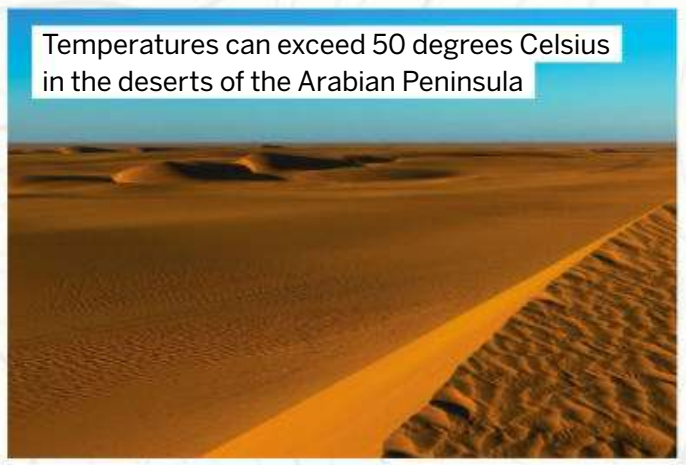
**FILTER**
As the air will be inhaled, it's first filtered to remove any dirt particles.

**FAN**
To keep the air flowing, a fan blows it through the helmet.

**COOLING MODULE**
This thermoelectric module transfers heat between its two halves. When an electric current runs through this device, all the heat moves to one side, making one half hot and the other cold.

**AIR DISTRIBUTION**
After the air is cooled by the module, it travels through large gaps in the fabric, reducing the temperature at the surface of the competitor's head.

The Dakar Rally has taken place in temperatures up to 40 degrees Celsius. This can create temperatures 20 degrees hotter inside the cars



Temperatures can exceed 50 degrees Celsius in the deserts of the Arabian Peninsula

AR zone SCAN HERE

**DID YOU KNOW?** Mitsubishi is the manufacturer with the most Dakar Rally wins in the car category

## GREEN BY 2030

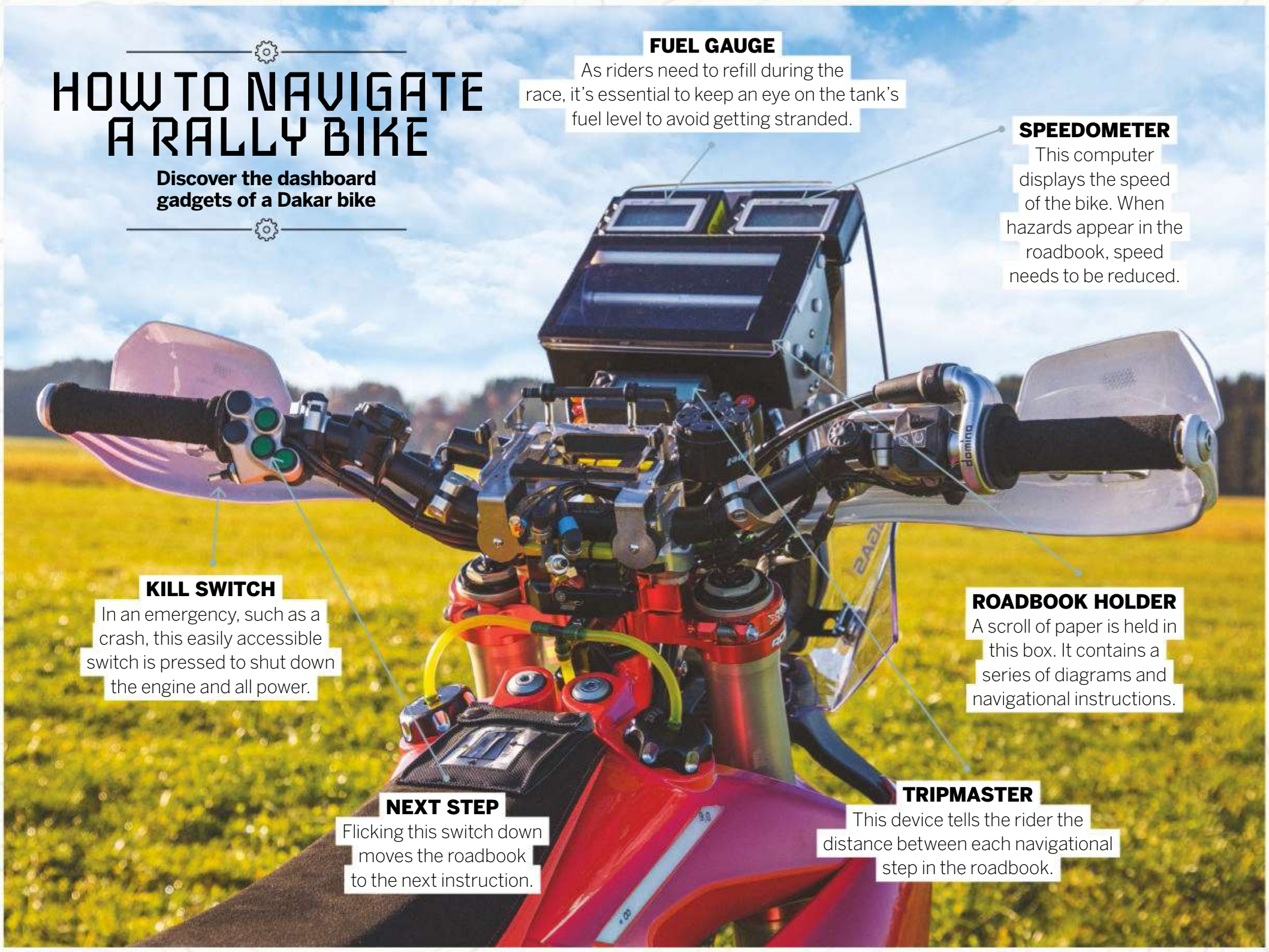
**The organisers of the Dakar Rally have launched 'DakarFuture', a plan to transition towards a lower emission event. In 2022 a new category – the 'alternative energy' category– could be added to the rally. This would include hydrogen-powered, electric and hybrid vehicles. In 2026 the car and truck categories will need to meet new requirements regarding their emission levels. The aim of this project is for all cars and trucks to run on green energy by the 2030 event.**

**Did you know?**
OSCar eO was the first electric vehicle to finish

The fully electric ACCIONA car completed the rally in 2017

## HOW TO NAVIGATE A RALLY BIKE

**Discover the dashboard gadgets of a Dakar bike**



**FUEL GAUGE**
As riders need to refill during the race, it's essential to keep an eye on the tank's fuel level to avoid getting stranded.

**SPEEDOMETER**
This computer displays the speed of the bike. When hazards appear in the roadbook, speed needs to be reduced.

**KILL SWITCH**
In an emergency, such as a crash, this easily accessible switch is pressed to shut down the engine and all power.

**NEXT STEP**
Flicking this switch down moves the roadbook to the next instruction.

**ROADBOOK HOLDER**
A scroll of paper is held in this box. It contains a series of diagrams and navigational instructions.

**TRIPMASTER**
This device tells the rider the distance between each navigational step in the roadbook.

© Getty / GasGas / Alamy / illustration by Adrian Mann

# AUTONOMOUS FREIGHT

## The world's first all-electric crewless cargo ship

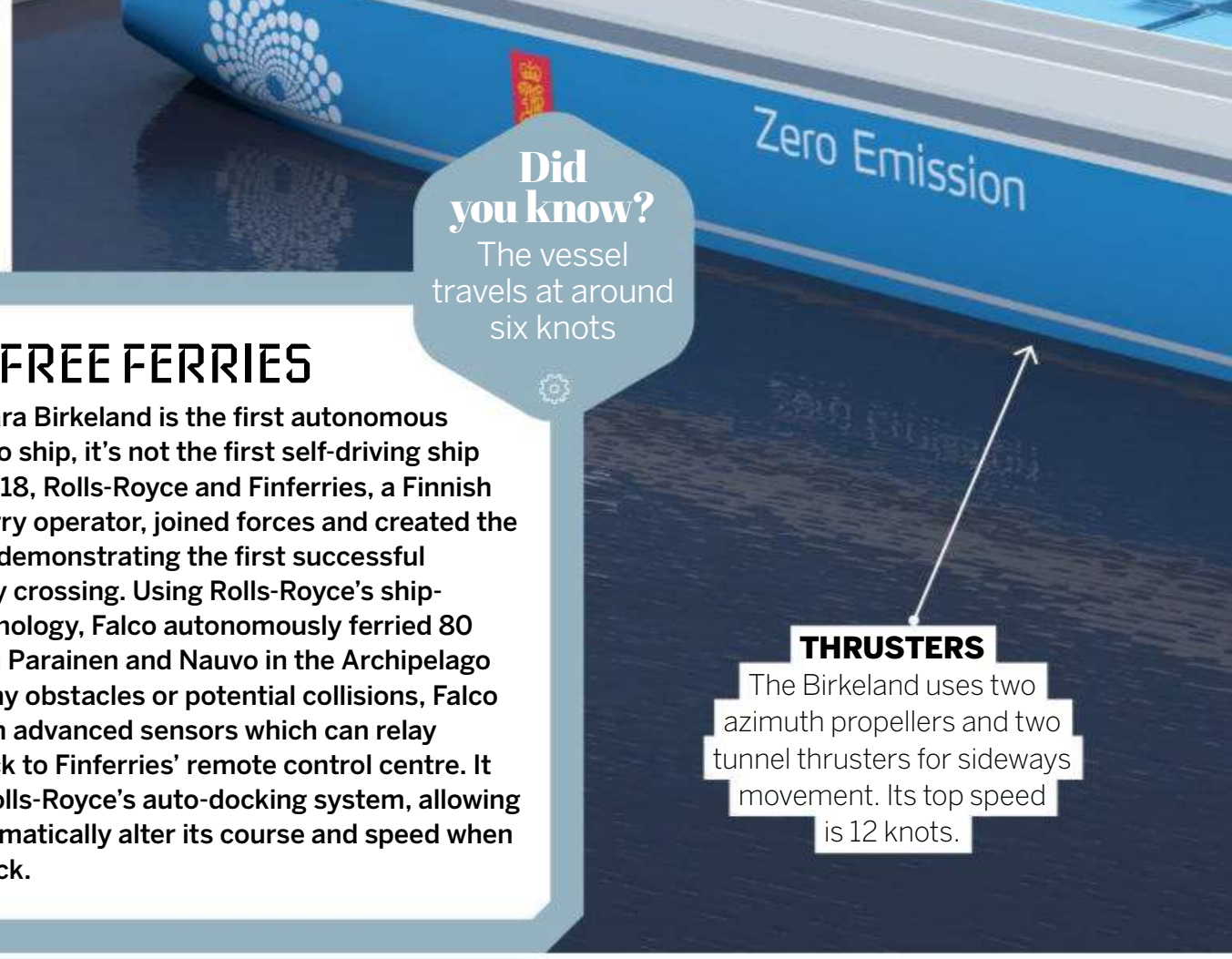
WORDS **SCOTT DUTFIELD**

In November 2021, the Yara Birkeland, the world's first autonomous electric container vessel, set off on its maiden voyage in Oslofjord, Norway. The 80-metre-long ship has been created by Yara International, a Norwegian chemical company, which will use the vessel to replace lorry haulage from its Norwegian plant in Porsgrunn to a port in Brevik, around 8.7 miles away.

The Yara Birkeland was announced in 2017 and promises to cut carbon dioxide ($CO_2$) emissions by 1,000 tonnes each year. This saving is equal to around 40,000 journeys made by diesel-powered lorries. Birkeland is an open-top container ship capable of transporting 120 shipping containers, also known as twenty-foot equivalent units or TEU - a total deadweight of 3,200 tonnes.

All of the cargo ship's systems, including the propellers and thrusters, are powered using electrical energy rather than burning the heavy fuel oil that's commonplace among cargo ships. The Birkeland can produce 6.8 megawatt hours of energy from its onboard batteries, equal to around 100 Tesla cars.

To handle autonomous technology, Yara teamed up with international technology group Kongsberg Gruppen. Using a range of sensors, Kongsberg has created a navigational system aboard Birkeland that allows it to not only automatically moor from port, but follow a preplanned route through the ocean and avoid obstacles or other sailing routes along the way. To ensure its safety, the vessel will be monitored by three centres of operation, all of which will be able to take control of Birkeland in case of emergency. The Yara Birkeland will begin its two-year commercial trial in 2022.




**AUTONOMOUS MOORING**
An automatic mooring system built into the Birkeland uses all the data collected from the onboard sensors to automatically adjust the vessel's movement to moor safely without human intervention.

**Did you know?**
The vessel travels at around six knots

**THRUSTERS**
The Birkeland uses two azimuth propellers and two tunnel thrusters for sideways movement. Its top speed is 12 knots.

## SAILOR-FREE FERRIES

The first automated car ferry, Falco, on its journey across part of the Archipelago Sea

**Although the Yara Birkeland is the first autonomous all-electric cargo ship, it's not the first self-driving ship to set sail. In 2018, Rolls-Royce and Finferries, a Finnish state-owned ferry operator, joined forces and created the car ferry Falco, demonstrating the first successful automated ferry crossing. Using Rolls-Royce's ship-navigation technology, Falco autonomously ferried 80 people between Parainen and Nauvo in the Archipelago Sea. To avoid any obstacles or potential collisions, Falco is equipped with advanced sensors which can relay information back to Finferries' remote control centre. It also features Rolls-Royce's auto-docking system, allowing the ship to automatically alter its course and speed when preparing to dock.**

**DID YOU KNOW?** The transport industry accounts for around 29 per cent of all greenhouse gas emissions in the US

## SCRAPPING BALLAST

**Traditionally, large cargo ships use ballast water to remain balanced. Ballast water is extra weight that's added to the ship to prevent it from bobbing out of the water like a cork. Water is pumped into the ship's ballast tanks from the ocean at the start of its journey and then dumped upon arrival at the ship's destination. However, this can negatively affect marine ecosystems. For example, invasive species can be transported to new ecosystems and wreak havoc. To minimise the ecological damage caused by ballast water, ships like the Yara Birkeland are sailing ballast-free, using alternative weights to steady the ship. In the case of the Birkeland, the battery packs that power the ship create the same stability as ballast water, therefore removing the need for it.**

A cargo ship discharging ocean water from its ballast tanks

## THE FUTURE OF MARITIME FREIGHT

**How the Yara Birkeland will autonomously ferry its cargo**

**LOADING AND UNLOADING**
Cargo will be loaded onto and removed from the ship using electric cranes.

**AIS**
The Birkeland is equipped with an automatic identification system (AIS) which tracks and transmits its real-time position, course and speed.

**RADAR**
Radar equipment emits electromagnetic waves, such as radio waves, and records the time taken for them to bounce off an object and return. This can establish distance and velocity.

**LIDAR**
Light is emitted from a rapidly firing laser. Similar to radar, lidar records the time taken for the light to return to judge distance. This sensor is typically used to scan the topography underneath a vessel.

Birkeland's cargo will be loaded and unloaded autonomously

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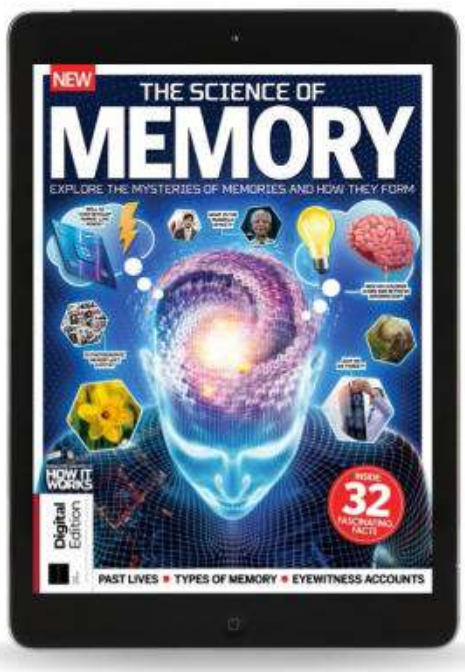
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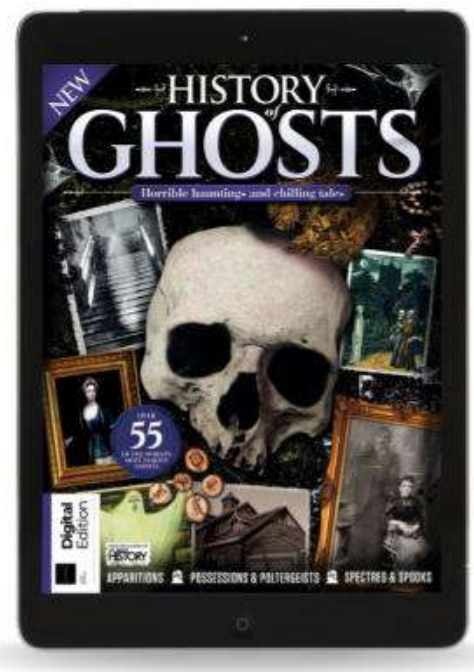


## History of Ghosts

This book is packed with spooks, spectres and horrible hauntings. Discover the history of ghosts and their believers from the ancient world to the present day. Find out why people believe in ghosts and possible scientific explanations behind haunted houses, spectral lights, scary sounds and spooky apparitions. Explore hoaxes and horrors from some of the world's most eerie locations and delve into stories of the phantoms, wraiths and spirits that are thought to frequent them.

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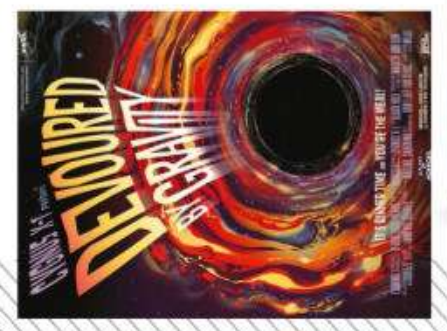

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# HOW ANCIENT LANGUAGES ARE DECIPHERED

## It took more than 20 years to translate the Rosetta Stone

WORDS **OWEN JARUS**

Some ancient societies had written languages, but deciphering their texts can be an almost-impossible task. So how do experts figure out how to translate ancient words into modern ones? The answer is multifaceted, but one famous example embodies some of the best practices: the decoding of the Rosetta Stone, discovered by a French military expedition in Egypt in July 1799, which helped pave the way to the decipherment of Egyptian hieroglyphs.

The stone contains a decree of Ptolemy V that was inscribed in three writing systems: Egyptian hieroglyphics, demotic script and ancient Greek. Written in 196 BCE, the decree stated that Egyptian priests agreed to crown Ptolemy V pharaoh in exchange for tax breaks. At the time, Egypt was governed by a dynasty of rulers descended from Ptolemy I, one of Alexander the Great's Macedonian generals. At the time the stone was discovered, both hieroglyphics and demotic script were undeciphered, but ancient Greek was known.

**Did you know?** Millions of visitors see the Rosetta Stone every year

The fact that the same decree was preserved in three languages meant that scholars could read the Greek portion of the text and compare it with the hieroglyphic and demotic portions to determine what the equivalent parts were.

When scholar Jean-François Champollion started studying hieroglyphs, he recognised that they could represent sounds. Since Champollion knew Coptic – the last stage of ancient Egyptian, written in Greek letters – he could figure out the sound value of hieroglyphs from the correspondence between the Egyptian hieroglyphs and the Greek translation on the Rosetta Stone.

**Above:** Ancient Egyptian hieroglyphs line the walls of tombs and temples

**Below:** Etruscan script can be seen carved above the entrances in the ancient city of Velzna

**Far right:** French scholar Jean-François Champollion

### DECIPHERMENT PROBLEMS

While Egyptian hieroglyphs were deciphered in the 19th century, there are still a number of ancient languages that are not understood today. There are three kinds of decipherment problems. Egyptian hieroglyphic writing falls into the category of a case in which the language is known, but not the script. Scholars already knew the ancient Egyptian language from Coptic, but didn't know what the hieroglyphic signs meant. Another decipherment problem is where the script is known, but not the language. Examples are Etruscan, which uses the Latin alphabet, and Meroitic, which uses a script derived from Egyptian hieroglyphs. In this case, we can read the words, but we don't know what they mean. The Etruscans lived in what is now Italy, and the Meroitics lived in northern Africa. The third type of decipherment problem is where neither the script nor the language are known. An example of this is the Indus Valley script from what is now modern-day Pakistan and northern India. Scholars don't know what the script is or what language it represents.

**DID YOU KNOW?** Scholar Jean-François Champollion discovered that hieroglyphs contained phonetic signs

# INSCRIBED IN STONE

**The Rosetta Stone is divided into three ancient scripts**

**EGYPTIAN HIEROGLYPHIC: 14 LINES**
Hieroglyphic writing contains signs that represent sounds and others that represent ideas.

**EGYPTIAN DEMOTIC: 32 LINES**
Meaning 'language of the people', this cursive Egyptian script was used for daily writing.

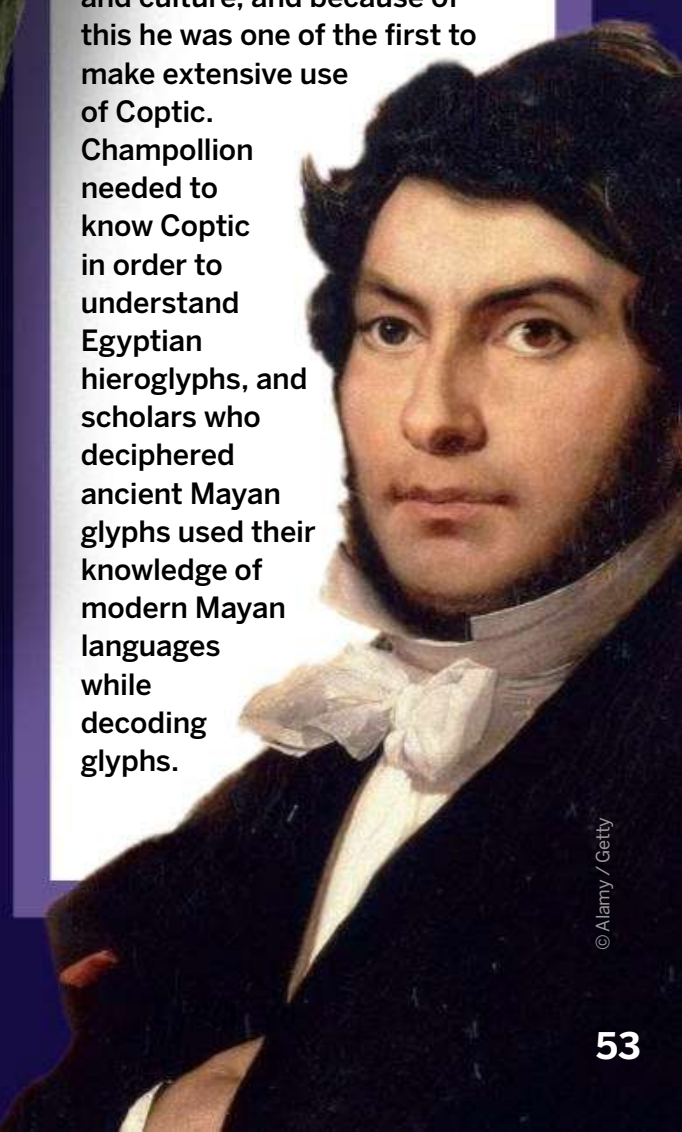
**PTOLEMY**
Encircled is the name Ptolemy, written from right to left.

**ΠΤΟΛΕΜΑΙΟΣ**
In the Greek section, Ptolemy is referred to as ΠΤΟΛΕΜΑΙΟΣ.

**ANCIENT GREEK: 53 LINES**
Greek was used by the Greco-Macedonian rulers of Egypt.

## PIECING THINGS TOGETHER

There are a number of lessons that scholars working on undeciphered scripts can learn from the decipherment of hieroglyphs. It's generally better to consider an ancient script in its cultural context. Thomas Young, a British scientist who also tried to decipher hieroglyphs, approached it like a crossword puzzle because he wasn't interested in ancient Egypt. Champollion was much more interested in Egyptian history and culture, and because of this he was one of the first to make extensive use of Coptic. Champollion needed to know Coptic in order to understand Egyptian hieroglyphs, and scholars who deciphered ancient Mayan glyphs used their knowledge of modern Mayan languages while decoding glyphs.



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# WHAT WAS THE BATTLE OF THE ALAMO?

## The outcome of this two-week battle between Mexican and Texian forces proved pivotal in the Texas Revolution

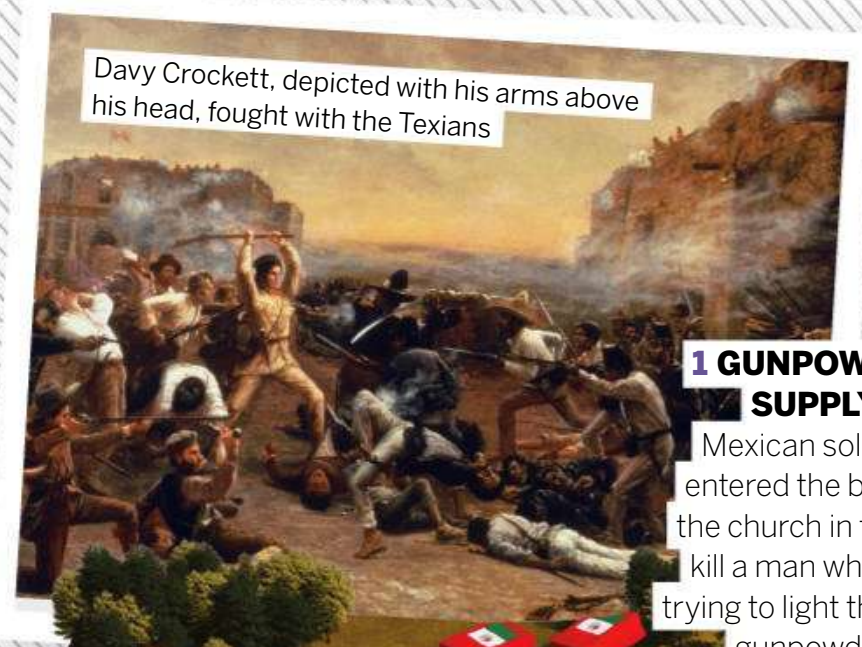
WORDS **AILSA HARVEY**

Between 23 February and 6 March in 1836, the Mexican army surrounded and attacked the Alamo. This old Spanish fort in what is today San Antonio, Texas, was occupied by Texan rebels, who were then called 'Texians'. Many of them had arrived in Texas from the United States and other countries, searching for land and new opportunities after Mexico gained its independence from Spain in 1821. Texas was under Mexican rule at the time of the battle, but its leaders sought independence after the Mexican government became a dictatorship under its new ruler, Santa Anna. Many Texians rebelled against the new government, initiating the Battle of the Alamo.

1,800 to 6,000 Mexican soldiers – their exact number isn't clear – arrived at the fort, which housed a defending force of less than 200. The Mexican army planned to recapture the town and put an end to the Texas Revolution. While the Texians lacked numbers, they displayed great determination.

When the Texians refused to surrender to the thousands of men besieging them, their attackers raised a blood-red flag – this meant 'no quarter'. For everyone in the Alamo, the only two options were victory or death. The battle began at dawn on 6 March and concluded around 90 minutes later.

The Texians suffered a brutal loss at the Battle of the Alamo, but it further motivated them to earn their independence. As they rebuilt their army, they developed a new battle call: "Remember the Alamo!" Their eventual victory came on 21 April at the Battle of San Jacinto.



Davy Crockett, depicted with his arms above his head, fought with the Texians

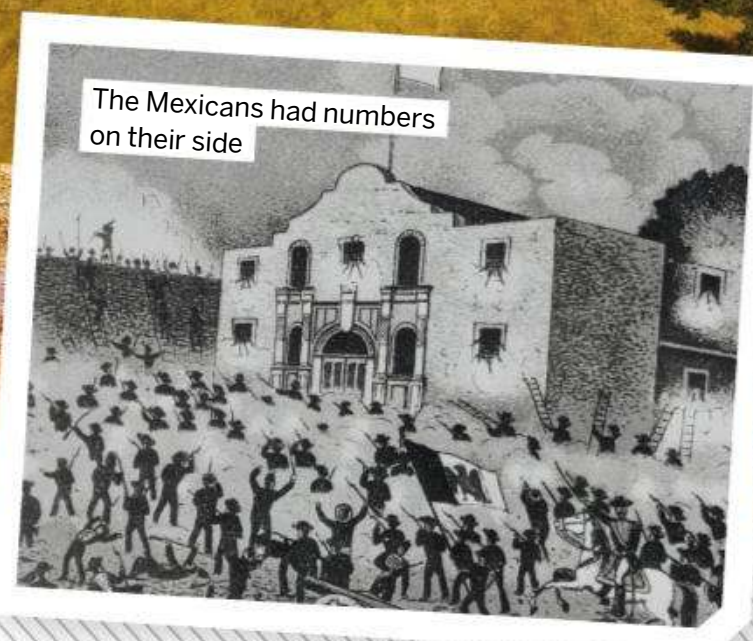
**1 GUNPOWDER SUPPLY**
Mexican soldiers entered the back of the church in time to kill a man who was trying to light the fort's gunpowder.

**10 SURROUNDING THE ALAMO**
Santa Anna's men surrounded the fort in a 13-day siege.

**9 PREVENTING ESCAPE**
Some defenders tried to flee the fort over the east wall, but were met by Mexican troops who were stationed to target escapees.

**8 ATTACK ATTEMPT**
At 05:50 on 6 March, Mexican troops charged towards the fort. Heavy fire from the Texians forced them to take cover beneath the walls.

**7 RAISED PLATFORM**
From the top of the north wall, cannons were fired at close range into the Mexican soldiers.



The Mexicans had numbers on their side

**DID YOU KNOW?** Defenders at the Alamo requested additional troops, but only 30 arrived before the battle commenced

# RECAPTURING THE FORT

**Track the offence of the Mexican forces as they surrounded the Texian rebels**

**2 FINAL POSITIONS**
Some of the defending troops were ordered to retreat to the church for a final fight. However, they were outnumbered and lacked weapons.

**3 DEFENSIVE RETREAT**
The Texian troops took secondary positions inside the fort's buildings.

**4 CAPTURE THE CANNON**
100 men, led by Colonel Juan Morales, climbed the walls here, taking control of the cannon before the Texians could disable it.

**6 SUCCESSFUL ENTRY**
After four failed attacks, some of the troops, including General Juan Amador, climbed over the north wall and opened a door for the rest of the attackers.

**5 WEST WALL ENTRY**
General Martín Perfecto de Cos' men broke windows and doors down with axes as they entered at different sections along this wall.

KEY

- Phase one
- Phase two
- Phase three

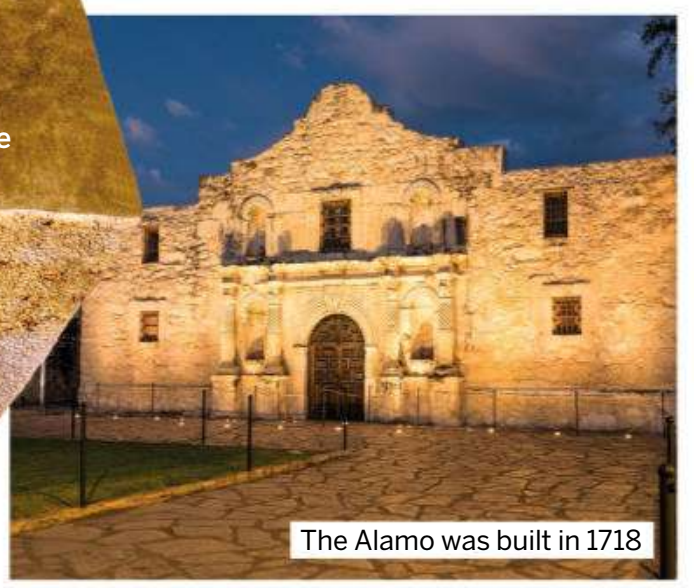
**Did you know?**
Between 600 and 1,600 Mexican troops were killed

## THE LEADERS

**The Mexican force was led by Antonio López de Santa Anna, while the Texians followed William Travis. Santa Anna became president in 1833 for his role in Mexican independence. By 1835 he had taken on the role of dictator, planning the invasion of Texas and ousting those who didn't follow him. As commander, Travis was killed with his troops. He rebelled against Mexican rule and became one of the first to sign up to the Texan forces. While surrounded, Travis wrote a letter to the people of Texas: "The enemy has demanded a surrender at discretion... I have answered the demand with a cannon shot and our flag still waves proudly from the walls. I shall never surrender or retreat."**

Santa Anna called himself 'the Napoleon of the West'

Travis became a lieutenant colonel in the Texas army at 26 years old



The Alamo was built in 1718

© Alamy / Getty

# WHAT IS THE INTERNATIONAL DATE LINE?

## This imaginary line separates time, running from the North Pole to the South Pole

WORDS **TOM GARLINGHOUSE**

The international date line (IDL) is an imaginary line that runs along Earth's surface from the North Pole to the South Pole in the middle of the Pacific Ocean. When you cross it, you either gain or lose a day depending on which way you are travelling. If you're travelling westward you gain a day, and if you're travelling eastward you lose a day. For example, if a traveller moves eastward across the Pacific Ocean from Wake Island to the Hawaiian Islands on 2 December, they will jump backwards to 1 December as soon as they cross the IDL. If they were travelling in the opposite direction, they would arrive at Wake Island on 3 December. Although the traveller seems to move back or forward in time, there's no physics-defying magic going on here. The international date line is based on a rational, practical system of universal timekeeping that takes into account the movement of Earth around the Sun.

Earth rotates counterclockwise – from west to east – on its axis as it travels around the Sun. This means different parts of the planet receive the Sun's direct rays at different times; when it's noon on one part of Earth, when the Sun is at its highest in the sky, another part of the planet may be completely in shadow or experiencing sunrise or sunset. It also means that, theoretically at least, if you were somehow able to outrun Earth's rotation, which is a speed of roughly 1,000 miles per hour, you could experience perpetual daylight and never see darkness.

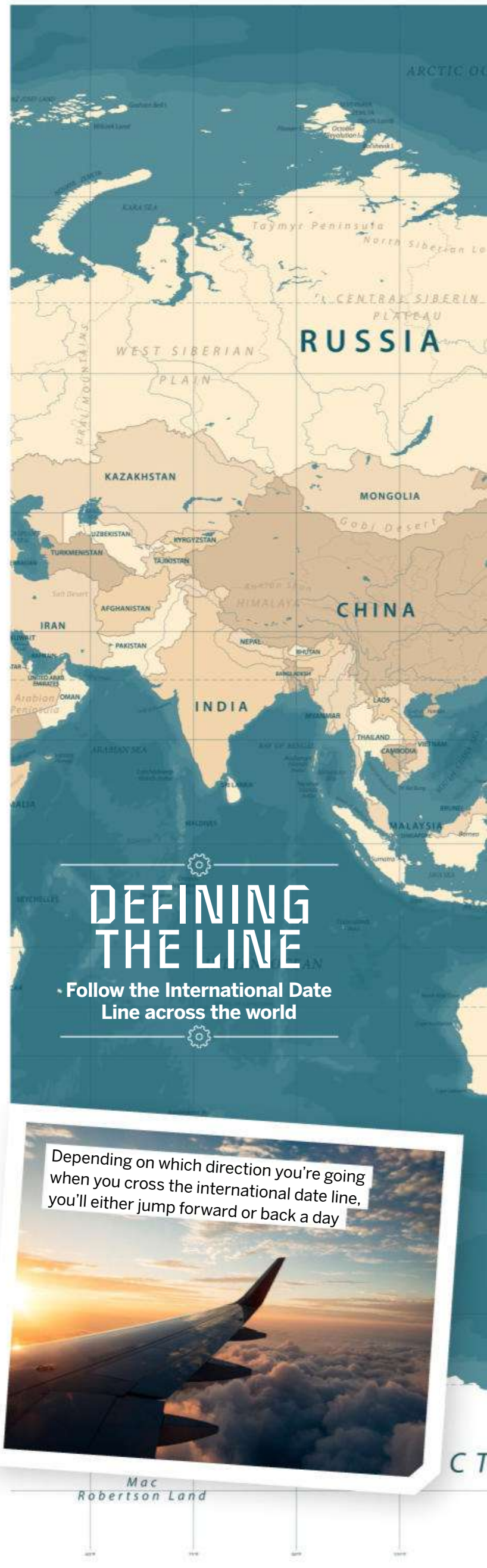
**Did you know?**
The IDL was based on the antimeridian

But humans don't travel at such great speeds, unless you are orbiting on the International Space Station - and when not travelling people generally stay in one place. To allow people to experience daylight hours in roughly the same amount – that is, to experience a normal day from sunrise to sunset - time zones are in use around the world.

Today we use a 24 time zone system. The logic of dividing Earth into 24 zones is derived from the fact that the planet is a sphere, and like any sphere it can be divided into 360 equal sections, or 360 degrees. Each time zone is measured as 15 degrees wide, and 360 divided by 15 is 24.

All of these zones are numbered consecutively eastward from what is called the prime meridian, which is a line of longitude that runs directly through the British Royal Observatory in Greenwich. The prime meridian, at zero degrees longitude, is the point from which all other measurements of longitude are taken. The prime meridian is also where the system of 24-hour timekeeping, called Greenwich Mean Time (GMT), originated.

As you travel east from the prime meridian, the time zones increase consecutively by one hour, or conversely decrease consecutively by one hour as you go west. But Earth does not go on indefinitely; eventually, a point is reached where you have to start over, or jump back or forward in time depending on your direction of travel.



**DID YOU KNOW?** The IDL has no legal international status, meaning countries are free to choose their own dates

**STARTING POINT**
The IDL runs roughly from the North Pole until it swerves through the Bering Strait, dividing Big Diomede Island in Russia and Little Diomede Island in the US.

**FOLLOW THE MERIDIAN**
The IDL roughly follows the 180-degree meridian, which is around halfway around the world from the prime meridian.

**SAME PLACE, DIFFERENT DAY**
There are only two miles between Big Diomede Island and Little Diomede Island. However, Big Diomede Island is always one day ahead of Little Diomede Island.

**HEADING SOUTH**
The IDL then moves beneath Alaska's Aleutian Islands and follows the 180-degree meridian south for several thousand miles before reaching the Pacific island of Kiribati.

**DEVIATION**
In a major deviation from the 180-degree meridian eastwardly, the IDL encompasses the Kiribati and Line Islands, also known as the Teraina or Equatorial Islands.

**SHIFTING THE LINE**
Until 1994, Kiribati was divided in half by the IDL, meaning that one half was a day ahead of the other. Seeking greater economic ties with Australia and New Zealand, the IDL was expanded eastward to encompass the nation's islands.

**FINAL STRETCH**
The IDL passes between Samoa and American Samoa before heading directly south. It rejoins the path of the 180-degree meridian after New Zealand all the way to Antarctica.

## DRAWING THE INTERNATIONAL DATE LINE

**The IDL was established in 1884 during the International Meridian Conference held in Washington DC. American President Chester A. Arthur convened the conference, which included representatives of 26 nations. The conference resulted in the recognition of the prime meridian in Greenwich, which had already been in use for several decades as the world's single 'initial meridian'.**

**In all, seven resolutions were passed at the end of the conference. These ranged from adopting a universal solar day – beginning at midnight in Greenwich and counting on a 24-hour clock – to the proposal that all nautical and astronomical days everywhere would begin at 00:00. The IDL was established as a result of the conference's Third Resolution, which stated: "That from this meridian longitude shall be counted in two directions up to 180 degrees, east longitude being plus and west longitude minus."**

The delegates of the International Meridian Conference, October 1884

© Getty

# BIGGEST NATURAL DISASTERS

## Eight times that nature caused widespread chaos and destruction

WORDS **SCOTT DUTFIELD**

Over the last decade, global natural disasters have accounted for 0.1 per cent of total deaths. Around 60,000 people die each year as a result of disasters such as drought, floods and earthquakes, and a further 150 million people are impacted by them.

A 'natural disaster' is characterised as a sudden event in nature, usually resulting in serious damage and loss of life. These events include geophysical hazards such as earthquakes and volcanic activity, climatological events such as wildfires and droughts and weather-related incidents such as storms and cyclones. Here are eight of the biggest natural disasters in history and the widespread chaos and devastation they caused.

An aerial view of raging bushfires

**DID YOU KNOW?** A devastating magnitude 9.5 earthquake occurred in Chile in 1960

# 2020 AUSTRALIAN WILDFIRES

Between 2019 and 2020, Australia experienced some of the deadliest wildfires in recent history. The official death toll for the wildfires themselves is 33, though a further 445 deaths were related to smoke inhalation and 4,000 people were admitted to hospital. Between September 2019 and March 2020, 46 million acres of South-Eastern Australian forests were burnt to the ground. The majority of the wildfires are believed to have been ignited by lightning, but the risk of intense fire weather during the bushfire season has increased by 30 per cent since 1900 as a direct result of climate change.

# SICHUAN MEGA-QUAKE 2008

Devastating several regions of south-central China, in May 2008 a deadly magnitude 7.9 earthquake ripped through the ground. Also known as the Wenchuan earthquake, it caused multiple landslides and building collapses across six provinces in China, leading to the deaths of almost 70,000 people. Destruction of infrastructure was also vast: more than 21,000 miles of highway was ruined, 1,263 reservoirs were damaged and 11,028 hospitals and clinics collapsed. It's estimated that the disaster had a direct economic cost equal to over £91 billion ($122 billion). At least 828 landslide dams were created by the earthquake, blocking rivers through the provinces. Military personnel struggled to remove these before heavy rainfall and flooding descended upon them.

Buildings lie abandoned after the earthquake

**Did you know?** There are around 55 earthquakes every day

Snowy Mount Huascarán

# 1970 HUASCARÁN AVALANCHE

On 31 May 1970, a magnitude 7.9 earthquake caused one of Peru's deadliest landslides. The quake emanated around 22 miles from Peru's highest mountain, Mount Huascarán. The force of the earthquake caused massive landslides that buried surrounding towns, particularly Yungay and Ranrahirca. It's estimated that cascading mountain ice and rocks sped down Huascarán at around 100 miles per hour, including a 700-tonne boulder that crashed into Ranrahirca. Up to 70,000 people lost their lives in the Ancash earthquake.

# 1986 POISON CLOUDS AT LAKE NYOS

Bubbling up from the depths of Lake Nyos in Cameroon, lethal clouds of carbon dioxide ($CO_2$) gathered on the water's surface before causing the deaths of almost 1,746 people and 3,500 livestock. Lake Nyos sits on top of a magma chamber, which leaks $CO_2$ into the water above. In 1986, a sudden eruption of 1.5 million tonnes of $CO_2$ gas burst from the lake, rolled down hillsides and smothered nearby villages. This is known as a limnic eruption and is a very rare natural phenomenon. Of the 845 people who survived the event but were admitted to hospital, 19 per cent were treated for lesions and bullae (blisters) caused by the $CO_2$.

## CHOKED BY $CO_2$

**How Lake Nyos suffocated its neighbours**

**1 STRONG WINDS**
Strong winds disturbed the surface water of the lake, and alongside heavy rainfall caused $CO_2$ to escape from the depths.

**3 $CO_2$ RIVER**
A deadly 50-metre-thick river of $CO_2$ flowed over 14 miles at speeds of between 12 and 31 miles per hour.

**4 SUFFOCATION**
$CO_2$ is denser than breathable air and can displace oxygen. When the $CO_2$ river drifted through villages, breathable air was substituted for $CO_2$ and people and animals died from asphyxiation – a lack of oxygen.

**STORED $CO_2$**
In the depths of Lake Nyos are dissolved gases such as $CO_2$. When pressure is released, gases can bubble out.

**VOLCANIC GAS**
Volcanic gases that leach out from molten magma beneath Lake Nyos, seep into the rock that surrounds the lake and travel into the water.

**2 ERUPTION**
The volcanic activity below the lake shifted the pressure and water flow within the lake, causing Landslides and phreatic eruptions of steam.

Suffocated livestock littered the landscape

© Getty / Alamy

After the disaster

Before Maria

# 2017
# HURRICANE MARIA'S FLOODING

On 20 September 2017, Puerto Rico was hit by the deadliest US-based natural disaster in the last 100 years. Hurricane Maria had the highest average rainfall of all 129 storms that have hit Puerto Rico in the past 60 years. The hurricane poured over a metre of rain onto the island, causing devastating floods. The death toll of Hurricane Maria was more than 4,600. Maria was also the third most costly tropical storm in the US, causing around £73 billion ($98 billion) in damages.

Thousands of homes were left in ruin

# 2005
# KASHMIR EARTHQUAKE

On 8 October 2005, the Kashmir region of Pakistan was hit by a magnitude 7.6 earthquake. Landslides triggered by the earthquake buried several towns and villages, including the two hardest hit, Balakot and Muzaffarabad. In Balakot, 90 per cent of buildings were demolished. In total, it's estimated that 3 million homes were destroyed throughout Kashmir, more than 86,000 people were killed and a further 100,000 were injured. It's believed that the sudden and rapid release of seismic stress between the Indian and Eurasian tectonic plates was the cause of the deadly earthquake.

**Did you know?**
There are 1,350 potentially active volcanoes worldwide

# 1815
# MOUNT TAMBORA'S 'YEAR OF WINTER'

When Mount Tambora in Indonesia blew its top on 10 April 1815, it resulted in the largest eruption in recorded history. It's estimated that 36 cubic miles of exploded rock was blasted into the atmosphere, which could have been seen from as far as 808 miles away. The explosion caused a year of winter due to expelled volcanic ash blocking heat from the Sun. As a result, temperatures in the Northern Hemisphere fell by around -17 degrees Celsius. Records indicate that the eruption caused 11,000 immediate deaths from pyroclastic flows (fast-moving solid lava, hot gas and ash) and a further 100,000 people died from food shortages over the following decade.

This caldera was left behind after the eruption

The storm ransacked buildings and infrastructure

# 1900
# THE GREAT GALVESTON STORM

On 8 September 1900, a storm swept through Galveston, an island city just off the coast of Texas. At the time Galveston was one of Texas' biggest port cities. However, a hurricane circulating with 140-mile-per-hour winds wiped it off the map. It's estimated that 3,600 houses and 600 businesses were reduced to rubble across 1,900 acres of land. This hurricane registered as a Category 4 on the Saffir-Simpson hurricane wind scale, which includes storms with sustained winds of between 130 and 156 miles per hour. Although it remains unclear exactly how many people perished during the hurricane, it's estimated the final death toll was between 6,000 and 8,000.

**DID YOU KNOW?** Hurricane Katrina is the most expensive US natural disaster, causing over $172 billion (£128 billion) in damages

# INSIDE THE VOLCANO

**How Mount Tambora's explosion blacked out the Sun**

**1 WATER INFILTRATION**
Cracks and fissures around the mountain fed groundwater into a magma chamber deep in the heart of Mount Tambora.

**2 BUILDING PRESSURE**
As water combined with magma, it was converted into steam, and the pressure beneath the mountain increased until it erupted in a enormous explosion.

**3 EARLY WARNING**
Tambora began emitting a small amount of ash and steam in 1812, three years before it blew its top.

**4 TWO-STAGE EXPLOSION**
The initial blast caused ash to reach heights of 22 miles. Several days later, another explosion sent volcanic debris even higher, flying 26 miles into the air.

**5 REDUCED HEIGHT**
The volcano was once more than 4,000 metres tall; the huge explosion brought it down to around 3,000 metres.

©Getty / Science Photo Library / Wim Williams Stepanov

A depiction of Doggerland's ancient residents

# HOW BRITAIN BECAME AN ISLAND

## The real Brexit started more than 8,000 years ago

**Did you know?** There have been five major ice ages in Earth's history

WORDS **SCOTT DUTFIELD**

Around 18,000 years ago, during the Pleistocene Epoch, the majority of modern-day Britain was covered in ice. This period of glaciation persisted for thousands of years, lasting until around 12,000 years ago after a warming climate brought the icy expanse to an end. In the wake of the ice age, today's North Sea and the English Channel were filled with grassy marshland, wooded valleys and swamps. This area of land, known as Doggerland, once connected Britain with mainland Europe and spanned over 18,000 square miles.

The beginning of the end for Britain's connection to Continental Europe began around 8,200 years ago when a massive tsunami struck Doggerland. Off the coast of Norway, an enormous underwater landslide known as the Storegga Slide shifted more than 720 cubic miles of material through the water – this is 300 times the annual sediment output from all the world's rivers.

The Storegga Slide was likely triggered by seismic activity following a period of deglaciation across Norway. The rapid movement and displacement of water caused by the slide generated enough energy to create the tsunami. The enormous wave would have reached heights of up to 20 metres. The tsunami swallowed up Doggerland, crashed into the northeast of Britain and travelled 25 miles inland, making it a newly formed island. It's largely accepted that the Storegga Slide-triggered tsunami is the predominant cause of the sinking of Doggerland and the separation of Britain and mainland Europe. However, some studies have found that something else may have severed the final link between the two.

By analysing the seabed and its sediments, researchers at the University of Bradford have discovered that the tsunami might not have been solely responsible for sinking Doggerland. Following the flooding, several smaller islands formed a 'Dogger archipelago', which remained for almost a thousand years. Between 8,400 and 8,200 years ago, the global average sea level rose – possibly in two phases – between one and four metres. This rise in sea level was linked to climate change, and by around 7,000 years ago the Dogger archipelago would likely have completely disappeared under the sea.

How Doggerland changed between 10,000 and 7,000 years ago

### LIVING ON DOGGERLAND

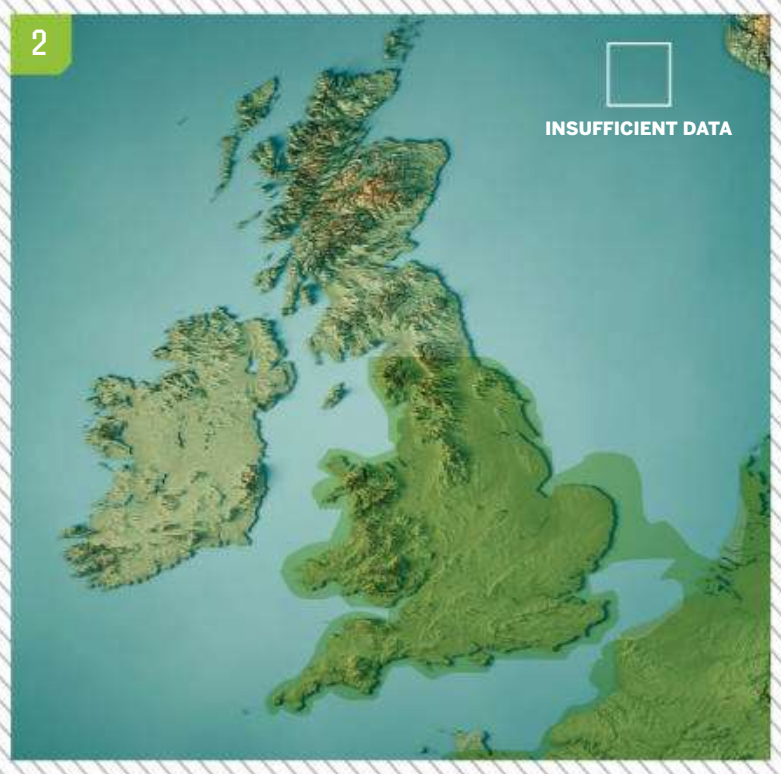
**When the Storegga tsunami hit the northwest of Europe, it not only drowned landmass, it also decimated ancient communities living on Doggerland. Human skeletal remains have been collected from fishing and dredging along the North Sea bed. Radiocarbon dating of the remains revealed that the majority belong to Mesolithic humans – living between 20,000 and 8,000 years ago – who resided on Doggerland. Archaeological evidence suggests that those who lived on Doggerland were hunter-gatherers.**

**At the time of the tsunami there would have been around 5,000 early humans scattered around Britain, who travelled from Continental Europe following the migration of mammoths and reindeer. Rising sea levels would have forced Doggerlanders to flee the lower lands – now sitting under the English Channel – and escape to higher landmasses in modern-day England and the Netherlands.**

**DID YOU KNOW?** During the last ice age, glaciers covered around eight per cent of Earth's surface

# DIVORCING EUROPE

**Britain's separation from the European mainland throughout the ages**



**1 450,000 YEARS AGO**
Britain underwent one of the harshest ice ages in its history, known as the Anglian Stage. Shallow valleys that spanned between modern-day France and England flooded as the ice melted, beginning the formation of the English Channel.

**2 400,000 YEARS AGO**
As global temperatures rose, evidence of an ice age melted away. This caused sea levels to rise, but Britain remained connected to Europe by a narrow land bridge. It was during this time that Neanderthals ventured into Britain.

**3 125,000 YEARS AGO**
Sea levels continued to rise, eroding the land bridge and eventually engulfing it. Britain became an island, but it was much smaller than it is today – most of Lincolnshire was underwater.

**4 60,000 YEARS AGO**
During this time, global ice had largely retreated to the poles, lowering sea levels, and once again Britain and Europe were married together with grass-covered plains. Over the thousands of years that followed, *Homo sapiens* made the trip across those plains into Britain.

**5 20,000 YEARS AGO**
The last ice age hit Britain, and the majority of its human population disappeared over the next 10,000 years.

**6 8,000 YEARS AGO**
Phases of sudden warm and moist global conditions brought about the end of the ice age. Britain and Europe split for the final time due to an enormous tsunami and the ensuing rise in sea levels.

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A common cuckoo (*Cuculus canorus*)

**Did you know?**
Around 40 per cent of cuckoos are brood parasites

# HOW CUCKOOS TRICK OTHER BIRDS

## Discover the cunning parenting of the cuckoo

WORDS **AILSA HARVEY**

Cuckoos are masters of deception. When it comes to raising young, they don't expend the energy building a nest, protecting eggs or feeding offspring. Instead the female passes these roles on to unsuspecting victims. These birds are brood parasites – they don't raise their own young. They lay their eggs in the nests of other species, tricking them into thinking the eggs are their own. Some of their main targets include dunnocks, meadow pipits and reed warblers.

To pull off this cunning stunt, the female cuckoo watches over her chosen nest to observe feeding times. When the host parent has left in search of food, the cuckoo will quickly lay an egg among those already in the nest. Sometimes she will even destroy and remove one of the host's eggs to make room for her own.

Cuckoos are birds in the Cuculidae family. They are medium-sized with long tails, and often have grey or brown backs. When they hatch and begin to grow in a host's nest, the difference in species can be obvious to an onlooker. Often the cuckoo is twice the size of its foster parent, but still continues to receive food from them.

The cuckoo imposter is usually the only hatchling that the host parent has to care for. This is because when the cuckoo hatches after around 11 days, it gets rid of all the other eggs in the nest. It will lift each egg onto its back before throwing them one by one over the edge of the nest. Even then, the non-biological parent will continue to treat the cuckoo as one of its own. After 20 days the cuckoo will leave the nest, but still receives food from its host.

### IS IT FOOLPROOF?

**Although the cuckoo's trick has a high success rate, some hosts are harder to fool. If a female cuckoo is spotted laying her eggs in the wrong nest, or the bird becomes aware that one egg is different, cuckoo eggs can be attacked. The host pierces the shell of the imposter egg and throws it out of the nest. In other instances, nests are abandoned and the cuckoo isn't fed.**

**Cuckoos sometimes lay their eggs outside of a nest. If an egg looks similar to the host's, this misplaced egg can be retrieved and placed into the nest. The likelihood that a chick will be rejected depends on the cost of raising the cuckoo. An example of this is when the cuckoo is much larger than its unsuspecting new parents. Feeding the cuckoo will use up much more of the host birds' energy.**

A marsh warbler feeding a much larger cuckoo chick

Cuckoo chicks can throw eggs out of nests by carrying them on their back

The larger cuckoo egg looks similar to the marsh warbler's

### EGG MIMICRY

**To intrude successfully, cuckoos have evolved disguises such as egg colouration. Cuckoos have evolved to produce eggs similar in colour to their main hosts'. This reduces the chances of eggs being attacked. Female cuckoos have been known to distract host birds after laying their eggs by making a noise similar to the Eurasian sparrowhawk, scaring birds away from returning to the nest and allowing time for the cuckoo to make its escape unspotted.**

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# WHAT IS QUANTUM COMPUTING?

## How the ability to be in two places at once is heralding a new era of ultra-powerful computers

WORDS MARK SMITH

**DID YOU KNOW?** The first dedicated quantum computer for business, 1QBit, was unveiled in 2012 in Vancouver, British Columbia

Imagine a new type of computer 158 million times faster than the most sophisticated supercomputer we have in the world today. A device so powerful that it could do in four minutes what it would take a traditional supercomputer 10,000 years to accomplish. This is the promise of new technology known as quantum computing.

For decades our computers have all been built loosely around the same design. Whether it's the huge machines at NASA or your laptop at home, they are all essentially just glorified calculators, and crucially they can only do one thing at a time. The key to the way all computers work is that they process and store information made of binary digits, called bits. These bits only have two possible values: a one or a zero. It's these numbers that create binary code, which a computer needs to read in order to carry out a specific task. But this is where quantum computing changes things.

This is because they use a branch of physics known as quantum theory, which deals in the tiny world of atoms and the subatomic particles inside them. When you delve into this minuscule world, the laws of physics are very different to what we see around us. For instance, quantum particles can exist in multiple states at the same time – this is known as superposition. Instead of bits, quantum computers use something called quantum bits, or 'qubits' for short. But here is the magic part... while a traditional bit can only be a one or a zero, a qubit can be a one, a zero or it can be both at the same time.

**Did you know?** The Sa 30 qubit can run trillions of operations per second

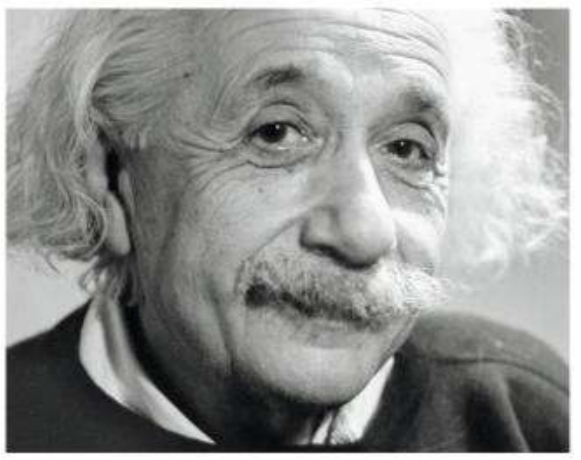
So what does this mean? Essentially, it means a quantum computer doesn't have to wait for one process to end before it can begin another; it can do them at the same time. Think of it this way: imagine you had lots of doors that were all locked except for one, and you needed to find out which one was open. A traditional computer would keep trying each door, one after the other, until it found the one which was unlocked. It might take five minutes, or it might take a million years, all depending on

## WHY DO WE NEED QUANTUM COMPUTING?

**In some ways, standard computers are pretty dumb. They can do what they are told to do well enough if they are fed the right computer program by a human. But when it comes to predicting things? Not so smart. This is why the weather forecast isn't always right. There are too many variables – too many things changing too quickly for any conventional computer to keep up.**

**Because of their limitations, there are some computations that an ordinary computer may never be able to solve, and others that might take it a billion years. Not much good if you need a quick prediction or piece of analysis. But a quantum computer is so fast – seemingly infinitely so – that it could respond to changing information quickly and examine a limitless number of outcomes and permutations simultaneously.**

**Quantum computers are also relatively small because they don't rely on transistors like traditional machines. They also consume comparatively less power, meaning they could be better for the environment.**



Even the great Albert Einstein was bamboozled by quantum behaviour

© Getty

how many doors there were. But a quantum computer could try all the doors at once. This is what makes them so much faster. As well as superposition, quantum particles also exhibit another strange behaviour called entanglement, which makes this tech potentially groundbreaking.

As well as speed, another advantage they have over traditional computers is size. According to Moore's law, computing power doubles roughly every two years. But in order to enable this, engineers have to fit more and more transistors onto a circuit board. A transistor is like a microscopic light switch that can be either off or on. This is how a computer processes the zeros and ones that you find in binary code.

But to solve more complex problems, you need more of those transistors. But no matter how small you make them, there's only so many you can fit onto a circuit board. Sooner or later, traditional computers are going to be as smart as we can possibly make them. That is where quantum machines can change things.

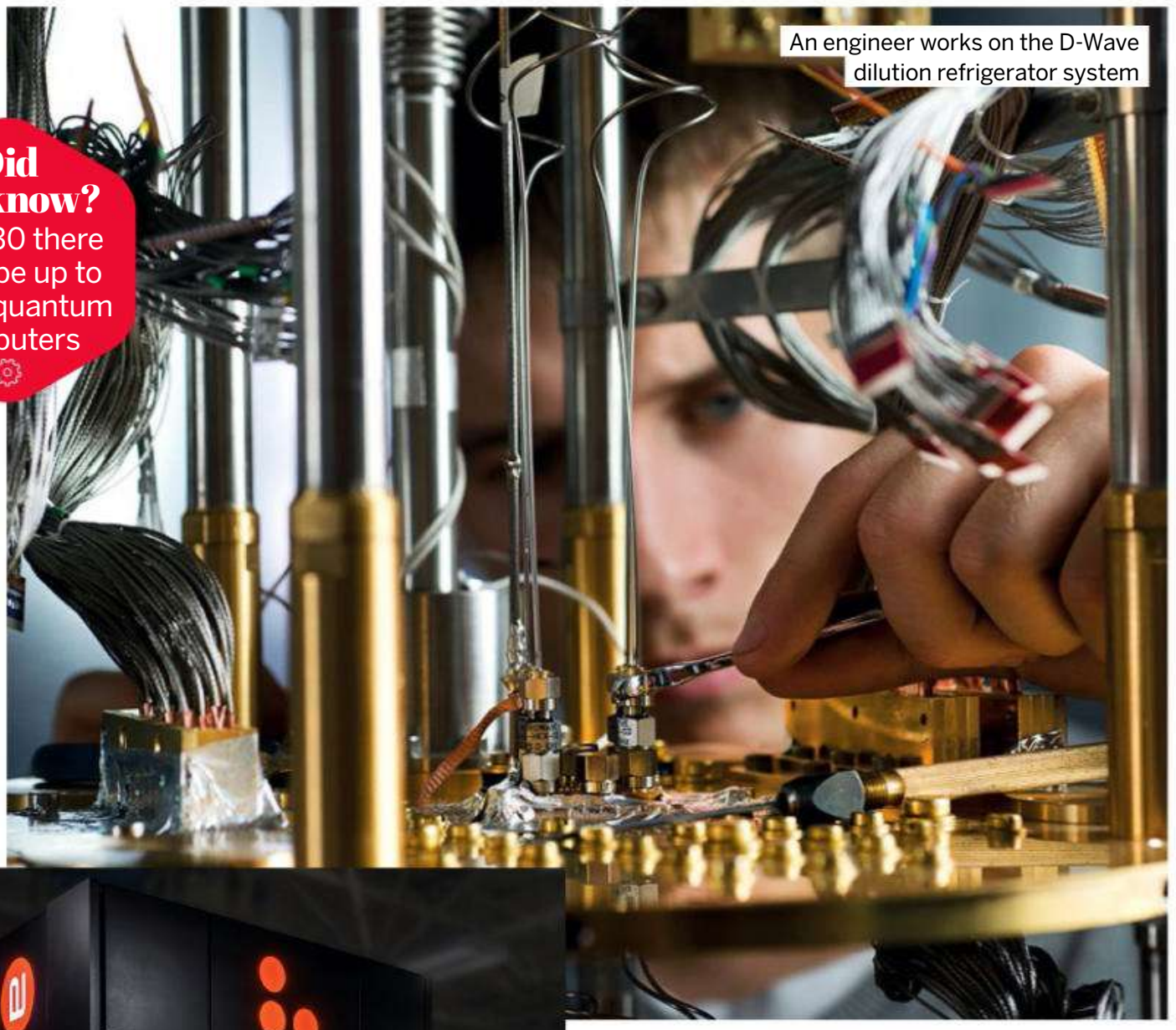
The quest to build powerful quantum computers has turned into something of a global race, with some of the biggest companies – and indeed even governments – on the planet vying to push the technology ever further, prompting a rise in interest in quantum computing stocks on the money markets. One prime example is a device created by D-Wave Systems. The Canadian company has built the Advantage system, which it says is the first and only quantum computer designed for business use. The company says it has been designed with a new processor architecture with over 5,000 qubits and 15-way qubit connectivity, allowing companies to solve their largest and most complex business problems.

D-Wave Systems says it is the first quantum computer that enables customers to develop and run real-world, in-production quantum applications at scale in the cloud. The Advantage is 30 times faster and delivers equal or better solutions 94 per cent of the time compared to its previous-generation system.

But despite the huge theoretical computational power of quantum computers, there's no need to consign your old laptop to the bin just yet. Conventional computers will still have a role to play in any new era, and are far more suited to everyday tasks such as browsing the internet, spreadsheets, emailing and word processing.

Where quantum computing could really bring about radical change, though, is in predictive analytics. Because a quantum computer can make analyses and predictions at breakneck speeds, it could perform fast traffic modelling and make far more accurate weather forecasts – things where there are millions if not billions of variables that are constantly changing.

**Did you know?**
By 2030 there could be up to 5,000 quantum computers


An engineer works on the D-Wave dilution refrigerator system

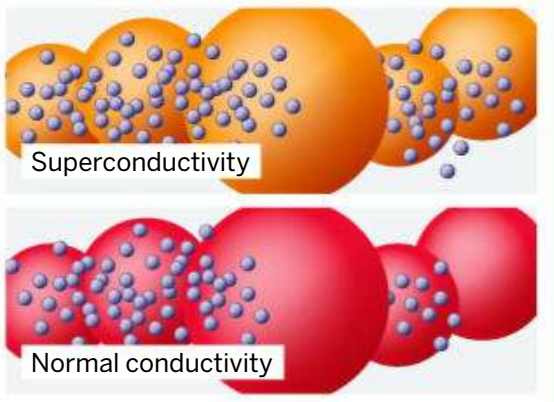
The D-Wave Advantage is said to be the world's first quantum computer for business

**"A quantum computer can make analyses and predictions at breakneck speeds"**

## PERPETUAL ENERGY

**One of the challenges for quantum computing is that qubits are super sensitive. In order for them to be usable they have to remain in their quantum state, but this is easily disrupted by coming into contact with heat, electromagnetic fields or collisions with air molecules. Superconductors are the answer. But even with a good conductor, some charge is still lost due to resistance.**

**Because superconducting materials operate according to the bizarre rules of the quantum realm, they don't have any resistance, allowing a charge to flow through them without any of it dissipating and creating an endless flow of charge that doesn't disrupt the qubits.**

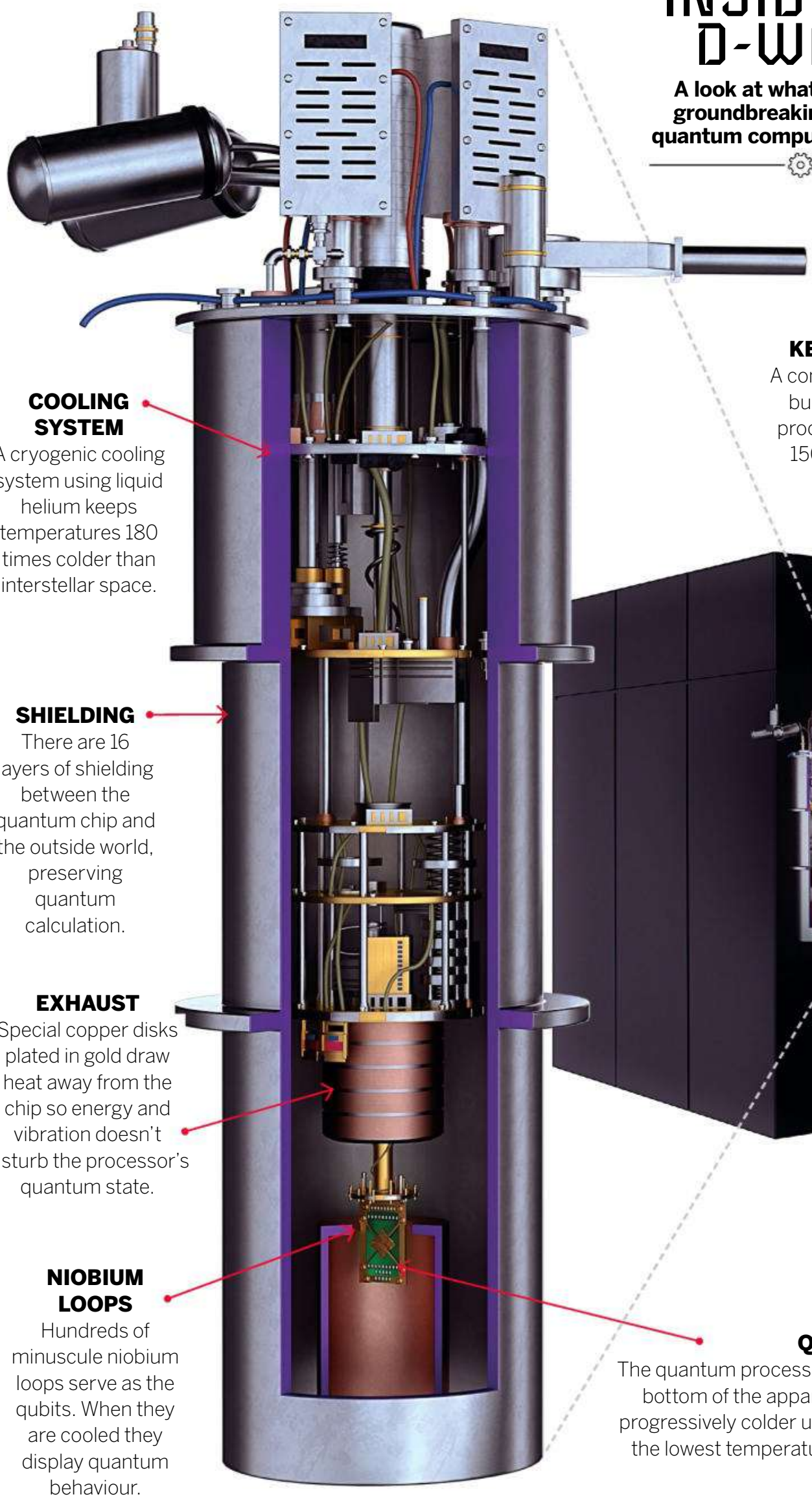

Superconductivity

Normal conductivity

**DID YOU KNOW?** Supercomputer Deep Blue could calculate 200 million chess moves a second; quantum computers can do around a trillion

# INSIDE THE D-WAVE

**A look at what makes the groundbreaking business quantum computer really tick**



**COOLING SYSTEM**
A cryogenic cooling system using liquid helium keeps temperatures 180 times colder than interstellar space.

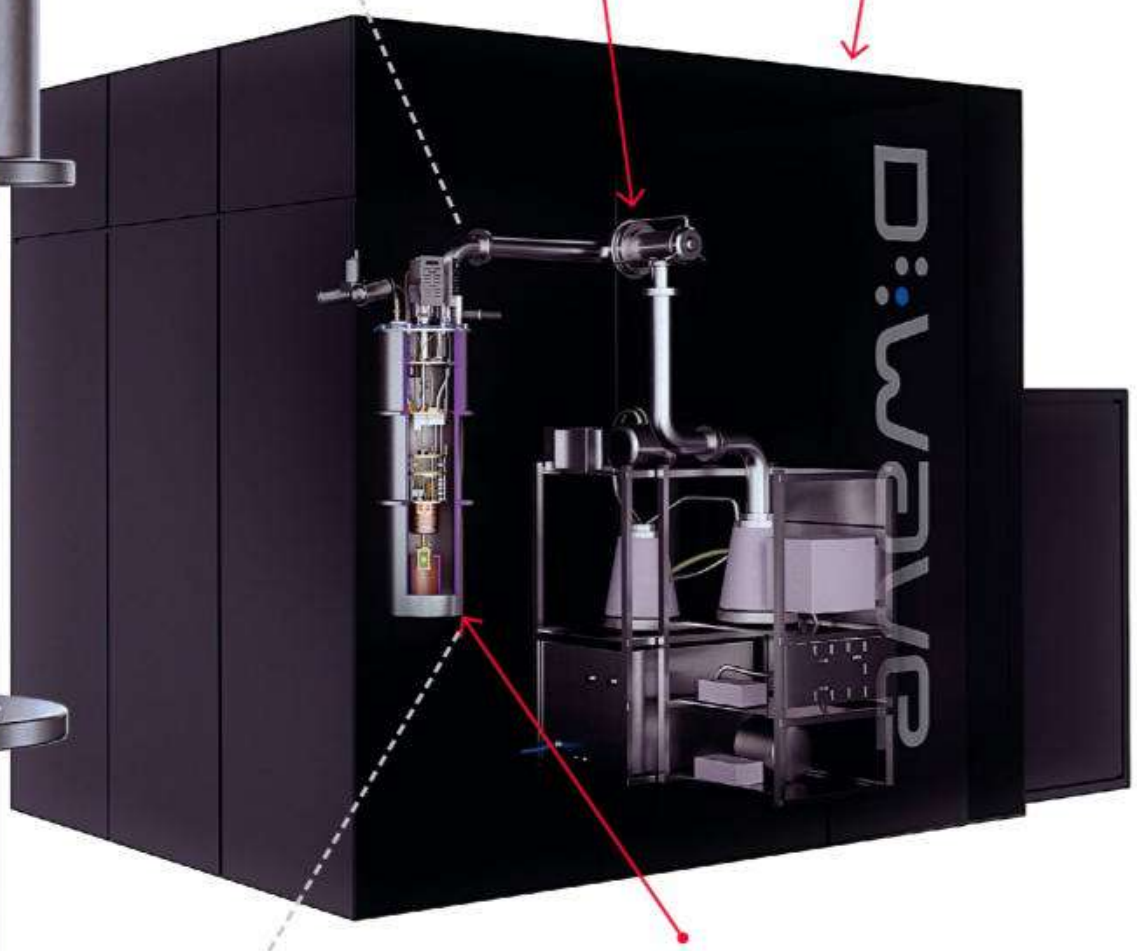
**SHIELDING**
There are 16 layers of shielding between the quantum chip and the outside world, preserving quantum calculation.

**EXHAUST**
Special copper disks plated in gold draw heat away from the chip so energy and vibration doesn't disturb the processor's quantum state.

**NIOBIUM LOOPS**
Hundreds of minuscule niobium loops serve as the qubits. When they are cooled they display quantum behaviour.

**SIZE DOESN'T MATTER**
Unlike traditional supercomputers, quantum computers don't need vast amounts of hardware so they can stay relatively small and eco-friendly.

**KEEPING THINGS COOL**
A complex refrigeration system is built in because the quantum process requires a temperature 150 times colder than space.




**NOISE SHIELDS**
The connecting wires have to be wrapped to shield them against magnetic fields which could disrupt the qubits.

**QPU**
The quantum processing unit (QPU) sits at the bottom of the apparatus which becomes progressively colder until near absolute zero – the lowest temperature physically possible.

AR zone

SCAN HERE

© D Wave / Illustration by Nicholas Forder

# DAWN OF A NEW ERA

Where quantum computers could really come into their own is where possible outcomes have to be calculated in huge numbers and at great speed. For example, predicting the flow of traffic through a huge city would be difficult for a standard computer because of all the data it would have to crunch – from roadworks and road layout to the day of the week, and even things like daylight and cloud cover. Other uses include weather and financial predictions, encryption, communications and cyber security.

The Chinese quantum satellite Micius was launched in 2016, serving as a trailblazer for the real-world application of quantum communications technology. Named after an ancient Chinese philosopher, it harnessed another quirky quantum behaviour known as entanglement. When two quantum particles are entangled, they form a connection to each other no matter how far apart they are. When you alter one, the other responds the same way – even if they're thousands of miles apart. Einstein called this particle property 'spooky action at a distance'. Using this entanglement process, scientists on the project were able to create a key to encode a message which could only be decoded using the other 'twin'.

In 2017, Micius was used to distribute quantum cryptographic keys to ground stations near Vienna and Beijing, enabling a secure virtual meeting between the Austrian and Chinese science academies, which were 4,600 miles apart. It's this type of technology that's opening up a whole new field of uncrackable communication which would allow messages to be passed away from eavesdroppers, be they rival governments and corporations or cyber criminals.

## TWINS OF LIGHT

**The first quantum satellite untangles a new way of encoding messages**

**ORBITAL EXPERIMENT**
The Micius communications satellite orbits Earth at an altitude between 310 and 1,240 miles.

**NEW INTERNET?**
Quantum communications creates the possibility of a new 'unhackable' quantum internet.

A satellite-to-Earth link was established between Micius and the quantum communication ground station in Xinglong

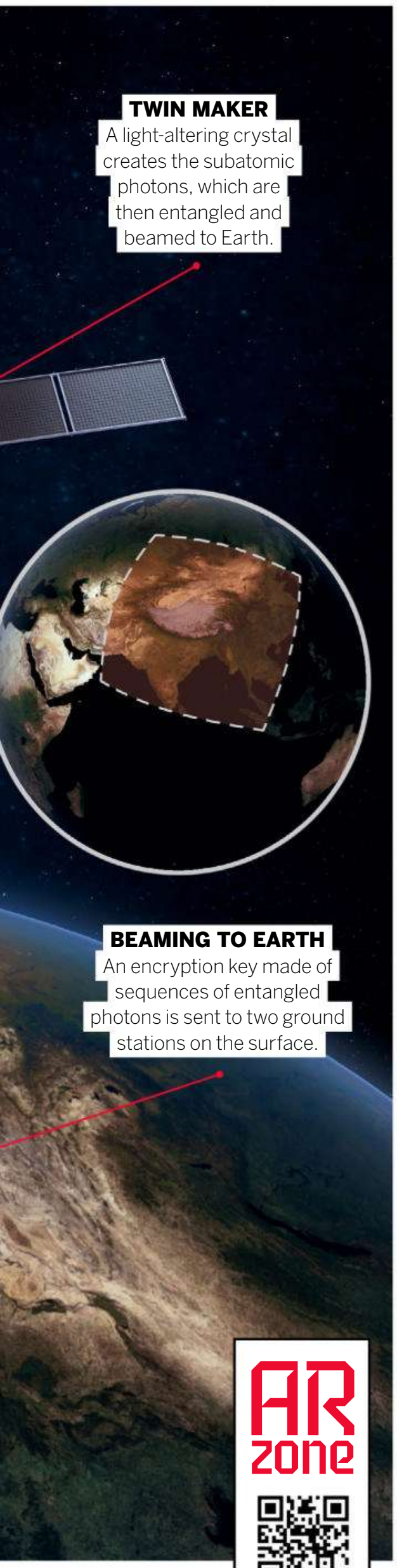
**QUANTUM ENCRYPTION**
Because changing an entangled photon would have an impact on its twin, the ground stations are able to know the key has not been messed with by hackers.

**Did you know?**
Quantum computers are not suitable for simple tasks

**"They form a connection to each other no matter how far apart they are"**

Entangled quantum particles mimic each other's behaviour even if they're thousands of miles apart

**DID YOU KNOW?** The D-Wave 2000Q system operates at 0.015 Kelvin, 180 times colder than interstellar space



**TWIN MAKER**
A light-altering crystal creates the subatomic photons, which are then entangled and beamed to Earth.

**BEAMING TO EARTH**
An encryption key made of sequences of entangled photons is sent to two ground stations on the surface.

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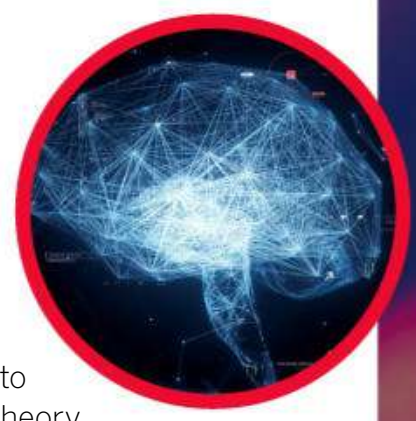
# USES FOR QUANTUM COMPUTING



### MAKING AI SMARTER

As well as quantum computing, another rapidly developing field is artificial intelligence (AI). But in order for the industry to grow, new ways need to be found to 'train' AI at speed. This is because for AI to learn, it has to take in lots of information. In theory, it could crunch numbers for 1,000 years to learn enough information in order for it to make its own decisions. But with quantum computing, AI could learn the same amount of information in a matter of seconds.

### CREATING NEW DRUGS

Crafting new treatments and pharmaceuticals can be a costly and time-consuming task. This is because at its most fundamental level, this type of scientific endeavour is all about trial and error. Scientists have to craft a new drug, test it, take the test data and begin all over again. Quantum computing could streamline that entire process. Scientists believe these types of advancements in quantum computing could make things a whole lot more efficient because simulations could be run and rerun at speed, with infinite permutations examined. This would also enhance safety and cost effectiveness.

### CYBER SECURITY

The more we live our lives online, the more we're open to cyber attacks. But quantum computing could create a new generation of impenetrable cyber defences. The sheer power of quantum computers means they could create uncrackable codes that no traditional hacker could penetrate. Quantum-era cybersecurity will also have the power to detect and deflect cyber attacks before they cause problems. The other side of the coin, though, is that a quantum computer in the hands of a hacker could possibly penetrate cyber defences.

# A QUANTUM FUTURE

Mark Johnson, vice president of Quantum Technologies and Systems Products at D-Wave, tells us what makes the Advantage so groundbreaking and why we won't be throwing away the traditional computer just yet.

**What's the difference between Advantage and a traditional computer?**
Advantage has the ability to harness quantum mechanics to solve problems. Advantage has upwards of 5,000 qubits, making it an incredibly powerful system. It only takes about 272 qubits to label every atom in the known universe with its own integer. Finding the solution to a 272-qubit problem is like finding the right atom out of all the atoms in the universe. It's hard to really comprehend how hard a 5,000-qubit problem could be, yet there are problems humans face that need this and more.

**What was the toughest part of developing Advantage?**
We launched our Advantage system in September 2020, which was a tremendous breakthrough for our company. Developing and building the system took more than 100,000 hours over a period of five years. The new architecture allows qubits to go from six-way connectivity in the D-Wave 2000Q to 15-way connectivity, allowing users to solve much larger and far more complex enterprise-level problems.

**What kind of use do you envisage for Advantage now and in the future?**
We continue to envision Advantage and other forthcoming systems from D-Wave as ideal quantum computers for business use. Our customers have seen success in financial services, pharmaceuticals and drug development, manufacturing, logistics and others. One of our customers, Menten AI, is creating the next generation of protein-based therapies using quantum computing. In the short term and in the longer term, we will all begin to benefit from quantum computing. From getting better personalised offers from companies who want to sell us things to finding new proteins to discover new therapeutics, quantum computing will impact us all.

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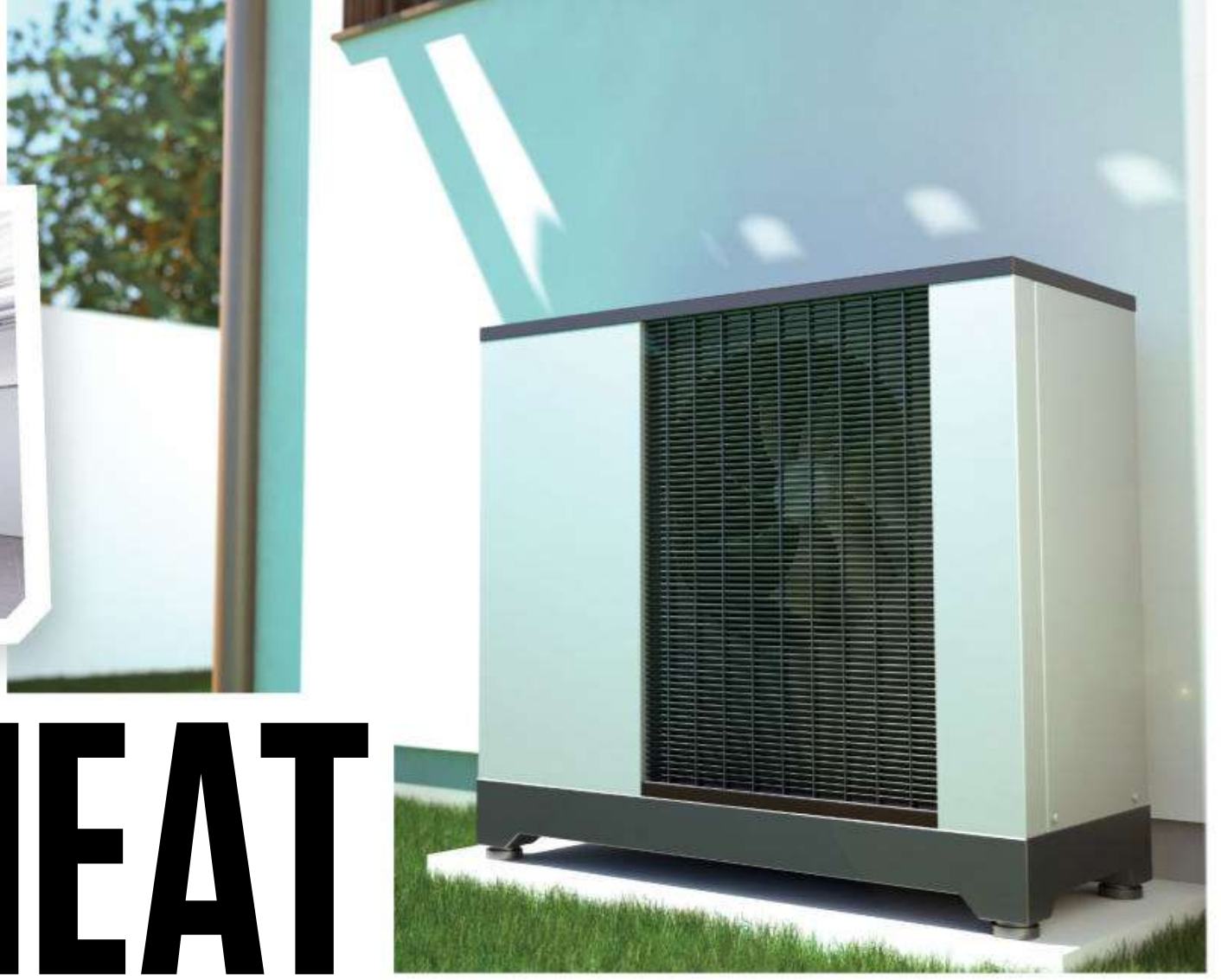


# HOW HEAT PUMPS WORK

## These machines use cold outdoor air to heat homes

WORDS **SCOTT DUTFIELD**

**Did you know?** Peter von Rittinger created the first heat pump system

Around 85 per cent of homes in the UK are equipped with a gas boiler, totalling around 26 million boilers nationwide. Each one of these boilers expels around 3.54 tonnes of carbon dioxide into the atmosphere annually from burning natural gas. Collectively, the UK's 26 million boilers pump out 92 million tonnes of carbon dioxide each year. The UK government has committed to zero emissions by 2050, and with this in mind there are calls for a ban on gas boilers as soon as 2025. But what could replace them?

Ready to take on the role are heat pumps. An air-to-air heat pump is a piece of machinery that extracts the energy from cold air and converts it into heat, which can be circulated throughout the home and heat water. Heat pumps are powered by electricity and use a liquid called a refrigerant to take thermal energy from outside, turn that energy into heat and then expel it indoors. Commonly used refrigerants are R134a and R-410A, which have incredibly low boiling points – R134a boils at around -26 degrees Celsius and R-410A at around -48 degrees Celsius. This means that most normal outdoor temperatures can cause them to boil into a hot vapour that can be pressurised to expel heat.

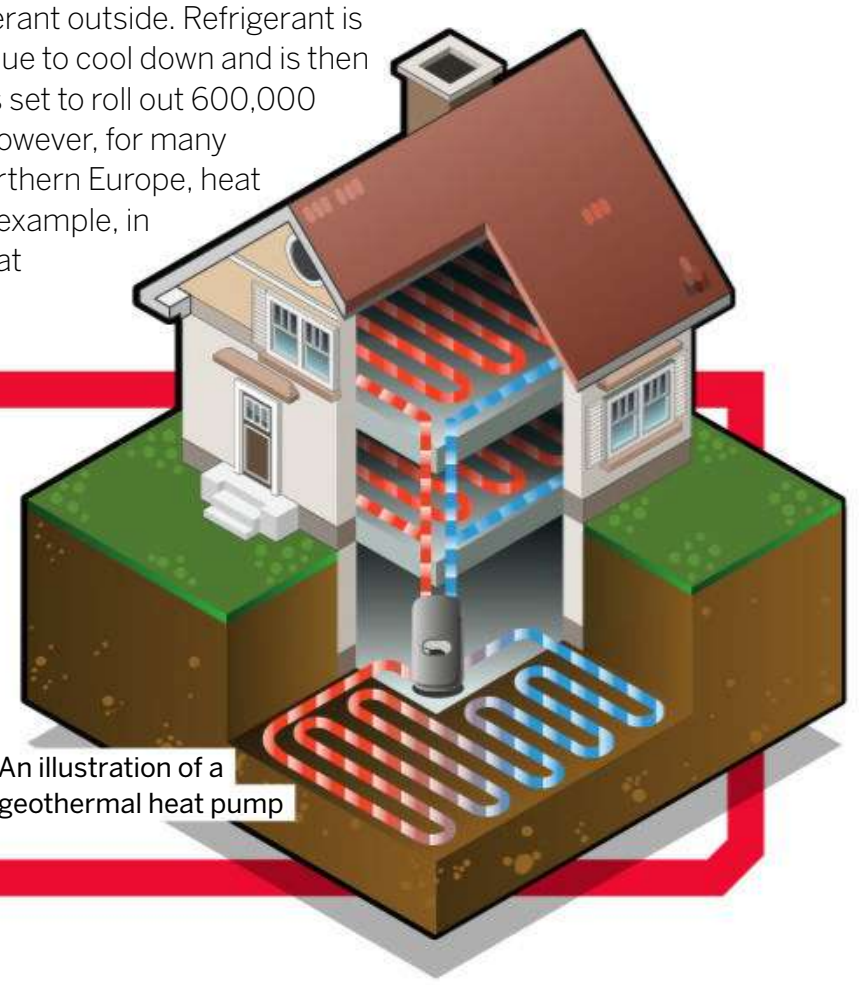
Similarly, when the temperature outside is hotter than indoors, these systems can quickly be transformed into air conditioners. The system is reversed: rather than forcing hot, vaporised refrigerant through pipes inside the house, a reversing valve diverts the refrigerant outside. Refrigerant is passed through an expansion value to cool down and is then fed inside. The UK government is set to roll out 600,000 heat pumps per year by 2028. However, for many countries across Central and Northern Europe, heat pumps are well-established. For example, in Sweden more than 1.9 million heat pumps are already in operation.

**Above:** The outdoor unit of an air-to-air heat pump

**Above left:** Heat pumps can also be used to heat or cool large commercial buildings like offices

### HOT ROCKS

**Air-to-air heat pumps are not the only home heating method. Water source heat pumps work similarly to air-to-air heat pumps, but extract heat between tanks of water rather than ambient air. Geothermal heat pumps, on the other hand, use stored solar energy trapped in the ground. This type of heat pump system uses a series of connected pipes called a loop, which is buried underground. As the cool refrigerant passes through the loop it's heated by the trapped solar energy and then fed into the compressor. Geothermal heat pumps are particularly efficient as ground temperatures are relatively constant throughout the year, regardless of season.**

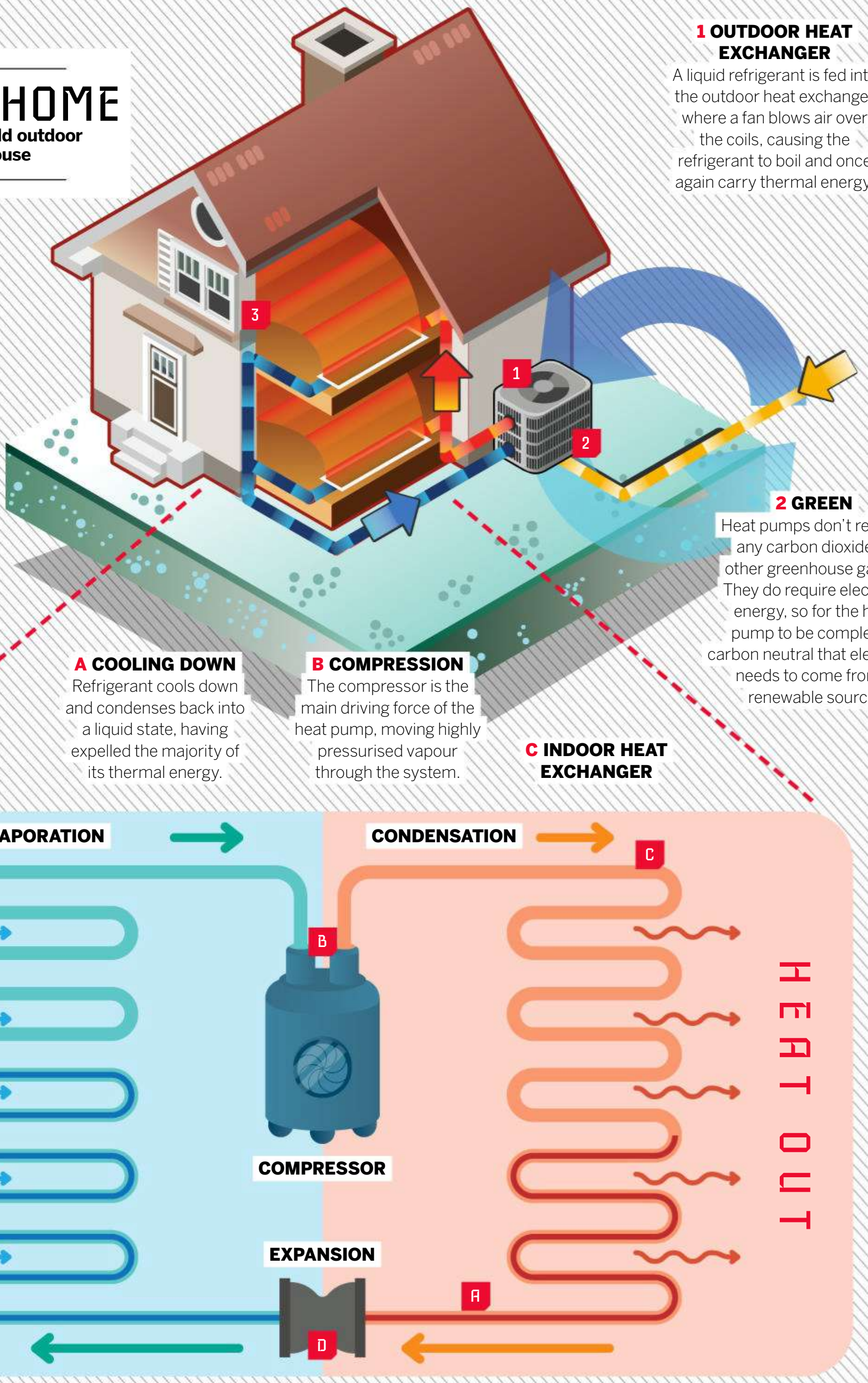


An illustration of a geothermal heat pump

**DID YOU KNOW?** Heating makes up 40 per cent of the UK's total energy consumption

# HEATING A HOME

**How heat pumps use cold outdoor air to heat up a house**




**1 OUTDOOR HEAT EXCHANGER**
A liquid refrigerant is fed into the outdoor heat exchanger where a fan blows air over the coils, causing the refrigerant to boil and once again carry thermal energy.

**2 GREEN**
Heat pumps don't release any carbon dioxide or other greenhouse gases. They do require electrical energy, so for the heat pump to be completely carbon neutral that electricity needs to come from a renewable source.

**3 INDOOR HEAT EXCHANGER**
Cool air within the home moves over the indoor heat exchanger, removing thermal energy and transferring heat to the rest of the room.

**A COOLING DOWN**
Refrigerant cools down and condenses back into a liquid state, having expelled the majority of its thermal energy.

**B COMPRESSION**
The compressor is the main driving force of the heat pump, moving highly pressurised vapour through the system.

**C INDOOR HEAT EXCHANGER**

**D EXPANSION VALVE**
As the liquid passes through the expansion valve, it expands, decreasing the pressure its under. This allows the refrigerant to boil at much lower temperatures.

© Getty

# HOW DOES A COFFEE MACHINE WORK?

## Take a look inside the Nespresso CitiZ coffee maker

WORDS **AILSA HARVEY**

For regular coffee drinkers, the availability and quality of a hot brew is important. Instead of waiting impatiently for a full kettle to finish boiling water, coffee machines can provide a more immediate, coffee-shop quality alternative.

These barista machines use small metal capsules filled with coffee, flavouring and sometimes milk, too. All that's left for the coffee drinker to do is make sure the machine is carrying enough water, select their preferred size and press the 'start' button.

The Nespresso CitiZ accommodates two sizes of coffee: a small 'Espresso' cup or a 110-millilitre 'Lungo'. These two settings are programmed so that the cup stops filling up just before the top. If a bigger or smaller volume is required, automatic pouring can be manually stopped or restarted.

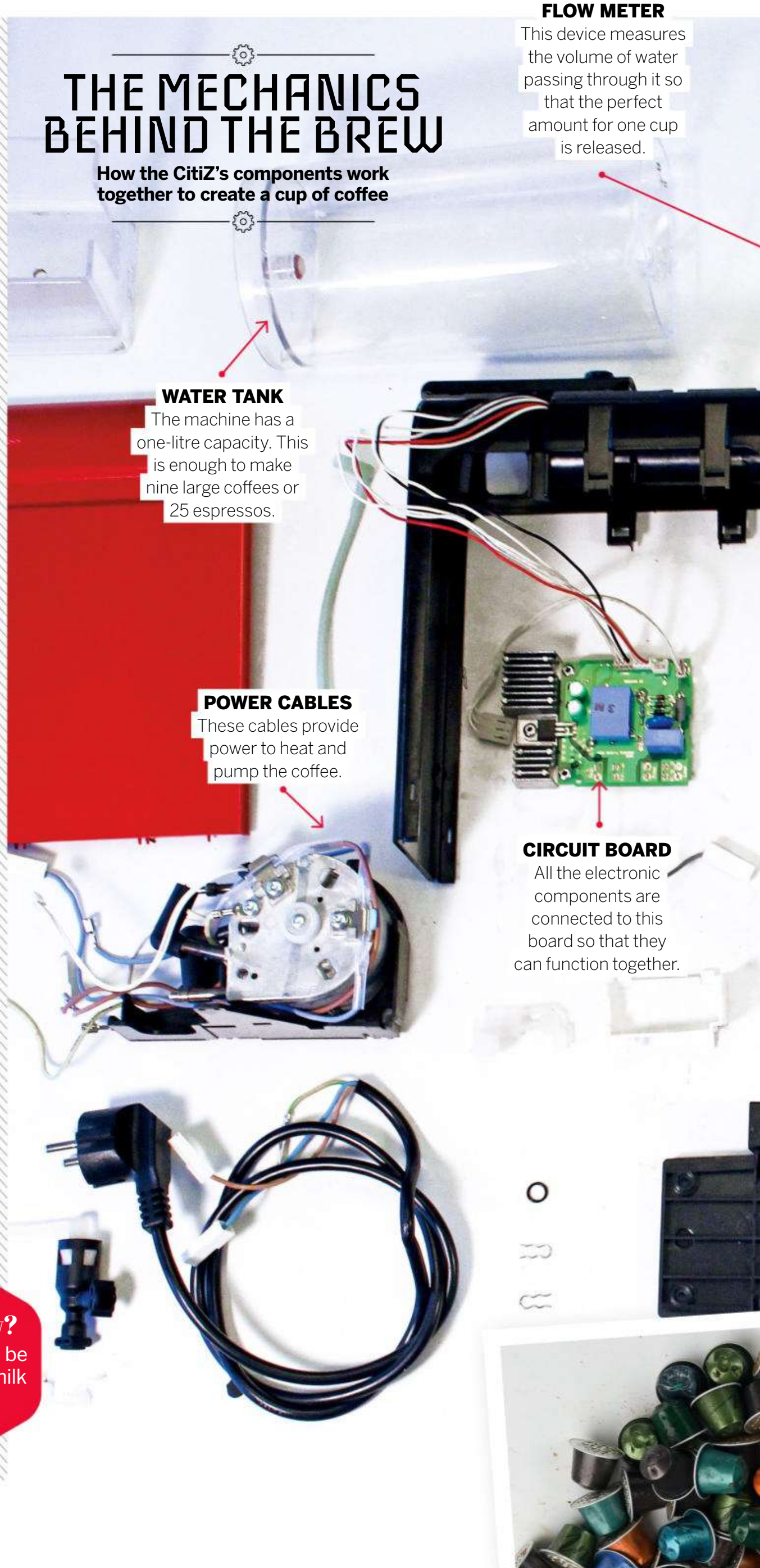
As the heated water passes through the coffee grounds inside the capsules, coffee is extracted. The higher the pressure, the faster the extraction of the oils and flavours. In most machines, a pressure of seven bars – seven times atmospheric pressure at sea level – or higher is needed for water to pass through the coffee grounds and produce coffee. In this CitiZ model, a 19-bar pressure is created.

When the coffee pod is empty, it's stored inside the machine until cleaned out. Around ten capsules can be used before the pods need to be removed and binned. To keep the machine clean, liquid sachets can be added to the water and the 'cleaning cycle' option pressed.

**Did you know?**
The CitiZ can be used with a milk frother

## THE MECHANICS BEHIND THE BREW

**How the CitiZ's components work together to create a cup of coffee**



**FLOW METER**
This device measures the volume of water passing through it so that the perfect amount for one cup is released.

**WATER TANK**
The machine has a one-litre capacity. This is enough to make nine large coffees or 25 espressos.

**POWER CABLES**
These cables provide power to heat and pump the coffee.

**CIRCUIT BOARD**
All the electronic components are connected to this board so that they can function together.

**DID YOU KNOW?** Nespresso coffee capsules are made from aluminium, which is recyclable and keeps coffee fresh

**FRONT SPOUT**
This directs the coffee into the cup. Some divide into two to allow more than one to be made at once.

**PUMP FEED TUBE**
Water is pumped through this tube so that it's strong enough to push through the packed coffee.

**WATER PUMP**
A magnet inside a metal coil powers the piston to push water through the machine.

**DRAIN GRATE**
The grates direct any spills into the drain below. For small cups, a grate can be installed closer to the spout.

Nespresso has a range of flavours in its coffee capsules

## A QUICK DRINK

**The Nespresso CitiZ coffee maker takes just 25 seconds to heat up after turning on. This means that all you need to do is add your chosen coffee capsule and press the start button to grab a hot drink.**

**Coffee machines are able to heat water quickly because only small amounts are heated at one time. Even though a full litre of water may have been poured into the container at the back of the machine, small volumes are pumped through the metal tube to be heated.**

**The machine also has an automatic shut-down feature. If it's left on for nine minutes without being used, the CitiZ will turn itself off to save energy.**

Only 40 millilitres of water is needed to make a Nespresso CitiZ espresso

There are two start buttons on the top, each delivering two different volumes of coffee

© iFixit / Alamy / Getty

# WATER ON MARS

**Orbiters and rovers have found evidence of a watery past on the Red Planet. But why is this evidence so important?**

WORDS JAMES HORTON

**DID YOU KNOW?** The Perseverance rover touched down on the Martian surface on 18 February 2021

The fourth planet from our Sun, Mars, is named after the Roman god of war, so dubbed because of its bloody-red colour. In 1897, novelist H. G. Wells wrote in his book *The War of the Worlds* that this colour was owed to organic red weeds that covered the planet's surface. However, when Mariner 9, the first spacecraft to orbit another planet, cruised around the red world, it revealed an endless landscape of dry, barren desert. In stark contrast to an abundant bounty of weed life, the reality of the Red Planet is a desolate biome covered in iron-rich dust and rocks.

But on and underneath the rocky surfaces, chasms and crevices of this world, there's a compelling mystery. The more we look, the more we find evidence that water may once have been abundant on Mars, and some think that liquid water is still hidden there.

Water is believed to be integral to the origin of life. Such is the importance of water that when exploring the Martian landscape, NASA adopted a similar strategy to Earth colonists exploring new lands, opting to 'follow the water'. Looking at the dry and barren surface, this strategy may appear misguided. But today's appearance doesn't mean the world was always this way.

Mars is a cold planet, 1.5 times as distant from the Sun as Earth. It's also smaller than Earth, and thus enjoys less gravity, meaning it only now retains a thin atmosphere. These factors mean that oceans could have once covered swathes of the dusty planet, yet these would be reduced to little or nothing today. Mars spacecraft, both orbiters and rovers, are therefore busy scouring the planet's geology and atmosphere for evidence of a former watery world.

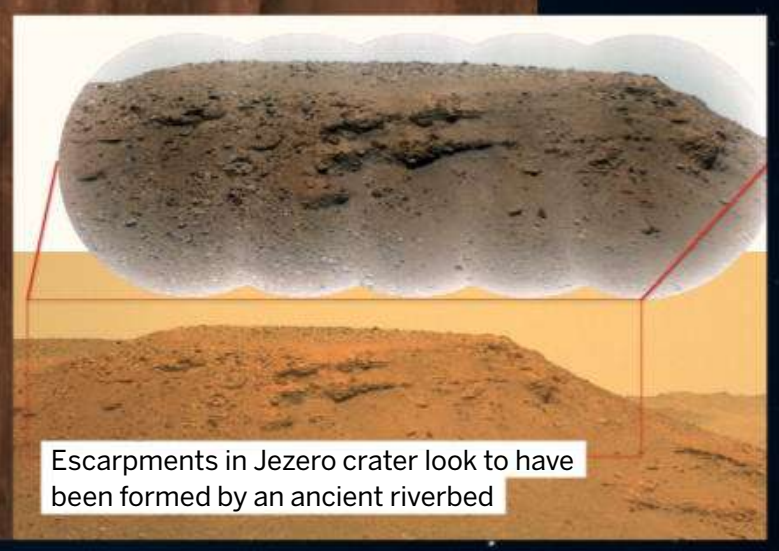
Geologists on Earth know that the flow of water leaves a powerful impression on the landscape. On a large scale, water carves out riverbeds as it moves across the land. On a smaller scale, water picks up and carries smaller minerals as it flows, slowly polishing them over time into smooth spheroids that are deposited somewhere downstream.

**Did you know?**
Some meteorites that fall to Earth come from Mars

Striking observations from the Mars Reconnaissance Orbiter (MRO) and its predecessors found evidence of large rock formations that appeared to be dry riverbeds. And the Curiosity rover has observed small, round stones littering a suspected former riverbed. As well as these features, an accidental discovery by the Spirit rover revealed a layer of silica – which is deposited by hydrothermal springs – nearby a suspected former volcanic hydrothermal region. The serendipitous finding reaffirmed for many scientists that the area was once home to a hot spring.

The ancient riverbeds of Mars are long since depleted, but water may have persisted

Seasonal dark streaks that appear in gullies, known as recurring slope lineae, may be formed by liquid water



Escarpments in Jezero crater look to have been formed by an ancient riverbed

Mars may once have been covered in oceans, and some water may persist on the planet

© Alamy / Getty / NASA/JPL-Caltech/University of Arizona / NASA/JPL-Caltech/LANL/CNES/CNRS/ASU/MSSS

in other forms into the modern day. The thin atmosphere would mean evaporated liquid water would soon be lost to space, but water could persist if the cold allowed it to freeze solid, or if it was protected underground. Like Earth, the poles of Mars are the coldest regions on the planet. But unlike Earth, temperatures on Mars can plummet to -150 degrees Celsius. This means that huge sheets of ice cover the poles of Mars. However, carbon dioxide freezes at these extreme temperatures, and approximately 95 per cent of the Martian atmosphere is composed of this molecule. Mars ice may be water ice, carbon dioxide ice or a combination containing both. The European Space Agency's Mars Express probe used infrared scans to help solve this riddle, revealing evidence of water ice existing in a cocktail with Martian dust at the southern pole.

While there may have been abundant oceans in the past and water ice persisting in the present, could there be lingering liquid water on Mars? Tantalisingly, the answer may well be yes. Using radar technology that penetrates the ground, returning signals suggested that bodies of liquid water also existed

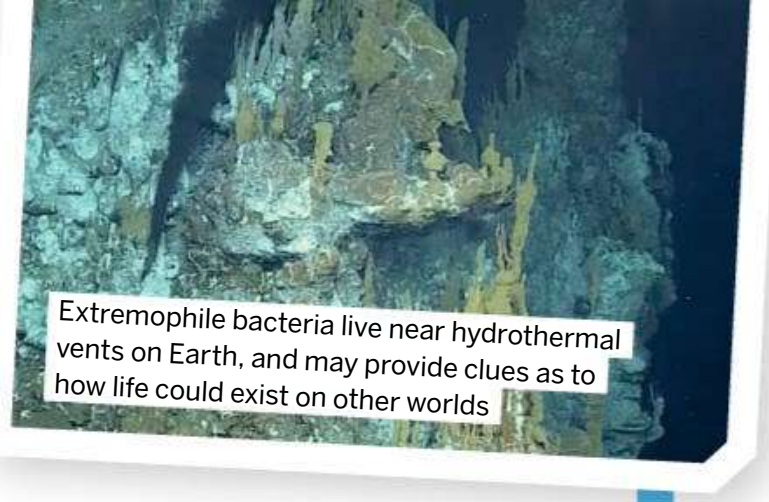
**"Remnants of water may endure on the Martian surface billions of years after it lost its oceans"**

underground the south pole. For water to be liquid at these temperatures it would have to be salty, almost a brine. But could such briny salt water also allow liquid water on the surface?

In 2011, the MRO captured images of dark streaks that appear seasonally in Martian slopes, which flow downhill. While some scientists argue that these streaks are owed to flowing sand, others believe they are owed to subsurface salt water that rises to the surface in more forgiving temperatures. Remnants of water may therefore endure on the Martian surface billions of years after it lost its oceans. The Perseverance rover is carrying this insight into the future of Mars exploration and will use these signatures of water on Mars as a guide for searching for ancient microbial life that may have once blossomed there.

## THE HISTORY OF WATER ON MARS

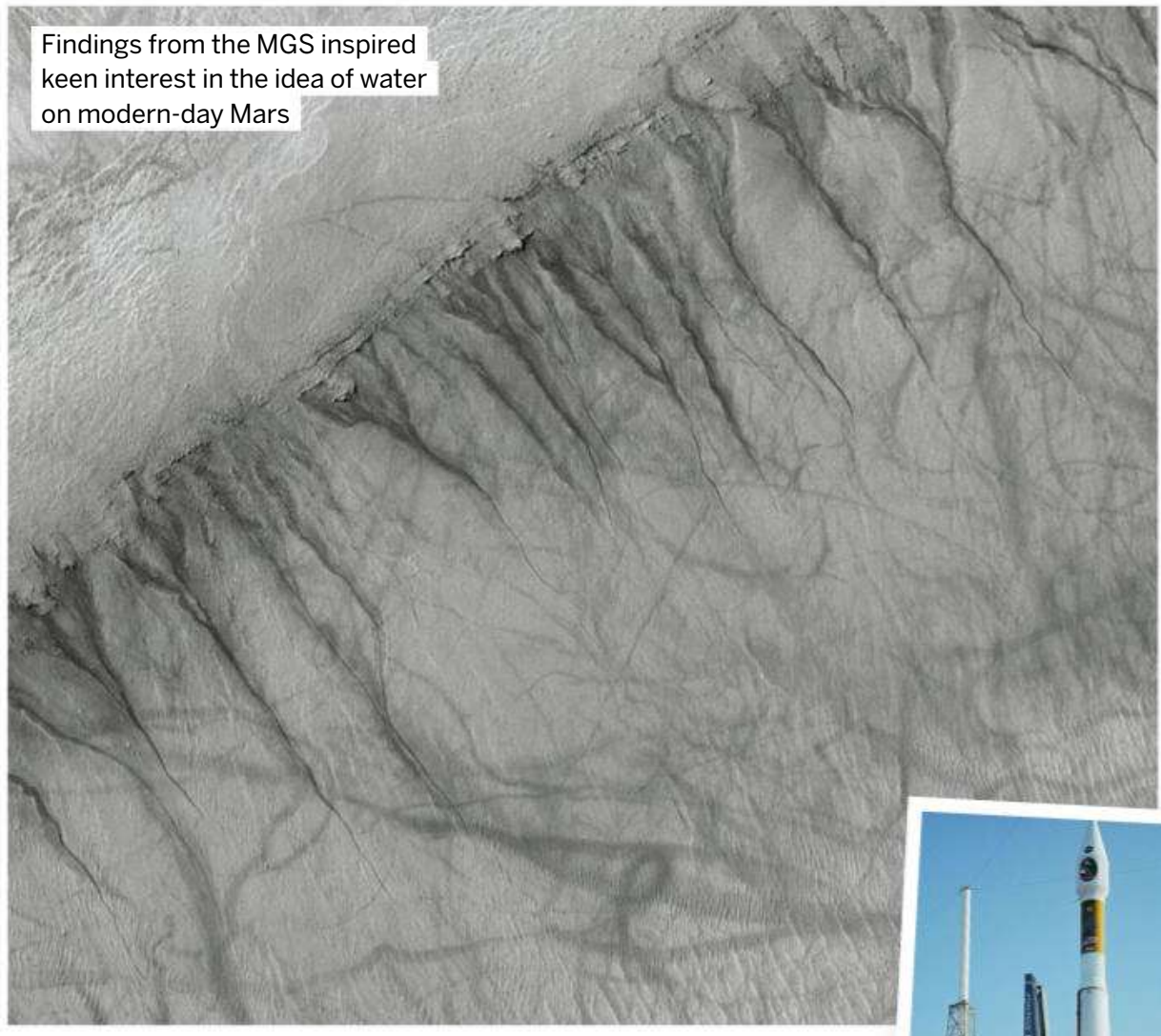
Evidence suggests that Mars was once covered in oceans that were lost several billion years ago


Extremophile bacteria live near hydrothermal vents on Earth, and may provide clues as to how life could exist on other worlds

## ASTROBIOLOGY ON MARS

The discovery of alien life would arguably represent the most significant discovery in the history of humanity. Most of the galaxy will likely forever remain out of our reach, but we may only need to peer across to our neighbouring planet to find it. Owing to the potential presence of liquid water, the hope for Mars is that conditions may have been sufficient to allow for the genesis and evolution of microbial life.

The idea of extant microbial life on modern-day Mars is highly suspect due to the pervasive arid and cold climate, which presents a hostile environment for life. However, research into extremophile microbes on Earth may offer clues as to how microbes could endure in salty water under the Martian surface. If microbes on Mars are now extinct, there's still much hope that we can find evidence of the biological relics they left behind, which would show that life could bloom on another world.


Findings from the MGS inspired keen interest in the idea of water on modern-day Mars

## EXPLORING MARS

**1971**
The orbital craft Mariner 9 photographed chasms on the Martian surface that resembled dry riverbeds.

**1997**
The Mars Pathfinder mission sent its last batches of data. The rover observed rounded pebbles that resembled minerals shaped in running water.

**2000**
The Mars Global Surveyor (MGS) probe took photos of gullies in Martian craters, which may have been formed by flowing water.

**2005**
The Mars Reconnaissance Orbiter (MRO) was launched from Earth, hosting a battery of instruments capable of detecting signatures of water on Mars.

**DID YOU KNOW?** NASA's policy of following the water is also guiding missions to other worlds in our Solar System

# WITNESS TUBES

One of the key mission directives during Perseverance's surface operations is to collect samples for a future mission to bring back to Earth. The rover will need to place the samples in the same designated location on the Martian surface, known as a sample cache. An important control measure is to make sure that scientists don't misinterpret Earth contaminants sent on the rover for something native to Mars. To ensure this doesn't happen, the rover is equipped with witness tubes, similar to sample tubes and opened at the same time. However, these don't collect any samples, instead taking in the ambient atmosphere at the sample site. Only if something is present in the sample tube and absent in the witness tube will it be considered native to the Red Planet.

## PERSEVERANCE'S SAMPLING SYSTEM

**The latest Mars rover will package up potential evidence of ancient life for a future mission**

**DEPOSIT**
The samples are deposited on the Martian surface for collection by a future mission when the rover reaches a 'sample cache depot'.

**SAMPLE CACHE**
The sample is transferred to the rover's belly, where it's inspected and sealed using a smaller, interior robotic arm.

**DRILL**
A large robotic arm attached to the rover's body drills the Martian surface to fill a sample tube.

**Did you know?**
The Saturnian moon Enceladus may also host liquid water

**CAMERAS**
Scientists controlling the rover on Earth decide on which samples to collect using cameras attached to the rover's body.

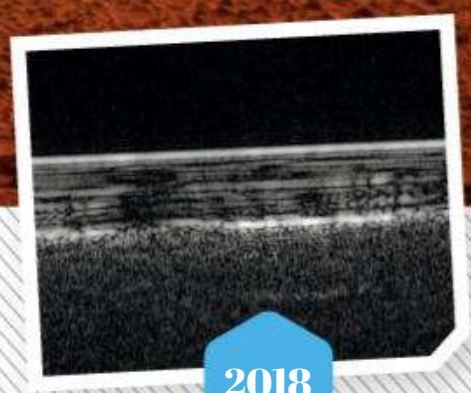
**2007**
The Spirit rover's broken wheel scratched away Martian soil (regolith), exposing silica – which usually forms in the presence of water – underneath.

**2008**
The Phoenix lander unearthed chunks of bright material that vanished after a few days; these may have been water ice.

**2011**
The Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment (HiRISE) imaged dark streaks on Martian slopes that changed seasonally.

**2012**
The Sample Analysis at Mars instrument (SAM) affixed to the Curiosity rover heated Martian dirt, finding signatures of water elements in the gases that boiled off.

**2015**
Lujendra Ojha and his colleagues performed spectral analysis on the dark streaks, which suggested that they were formed by salty liquid water.



**2018**
The European Space Agency's Mars Express orbiter used ground-penetrating radar to find signatures of underground water ice at Mars' south polar region.

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The spacecraft was carried on board an Atlas V rocket

## IMPORTANT INSTRUMENTS

**Lucy will carry four tools that will conduct experiments on the Trojan asteroids**

### 3 COLOUR SNAPS

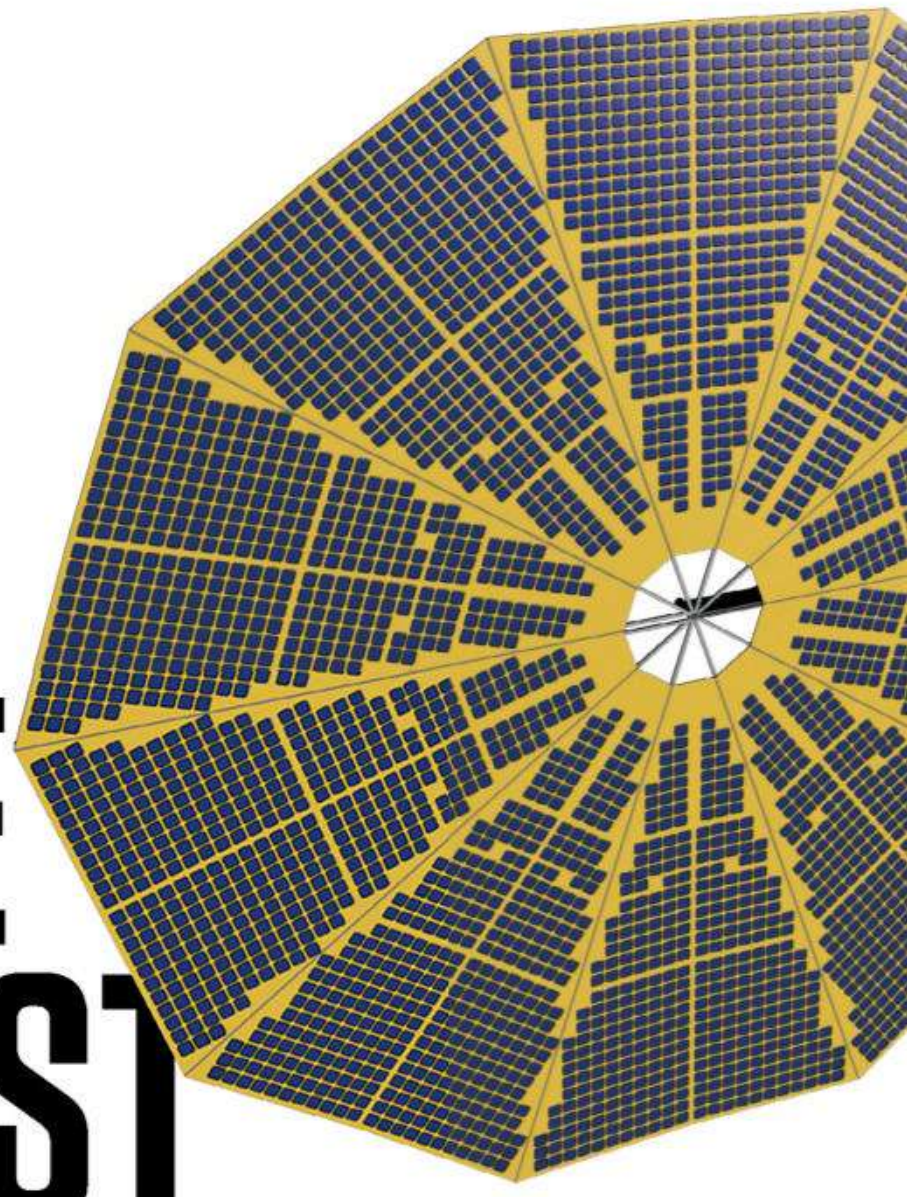
The L'Ralph module has two instruments – one camera to take colour images, and another to identify rocks, ices and compounds.

### 1 ANALYSING ASTEROIDS

Lucy's antenna uses radio signals to determine asteroid weights, and a camera takes wide images of each asteroid to show their shapes.

### 2 HEATING UP

The L'TES thermal spectrometer detects infrared radiation, functioning like a thermometer to provide insights about asteroid structure and materials.



# NASA'S SPACE ARCHAEOLOGIST

A mission is being sent to explore ancient asteroids that orbit alongside Jupiter. Here's everything you need to know about Lucy

WORDS **MIKE JENNINGS**

Lucy is an incredible space expedition that deserves your attention – it's going to explore the history of the Solar System and reveal more about life on Earth. Its launch took place on 16 October 2021. The spacecraft will fly 445 million miles away from Earth to explore swarms of asteroids that orbit the Sun in two groups: one ahead of Jupiter, and one behind. They're called the Trojan asteroids, and no spacecraft has ever paid them a visit before.

These asteroid clusters have been orbiting the Sun for billions of years; research shows that they're probably made from the same ancient material that originally formed planets like Jupiter, Neptune and Saturn. They're simple, but they're time capsules that could give humanity some incredible insights into the birth of the Solar System and the formation of life.

The Lucy mission's sheer distance means it's a long-term journey – the probe will fly past Earth on 15 October 2022, using our planet's gravitational pull in several different phases so it can be flung towards the Trojan clusters. Lucy will arrive at the Solar System's main asteroid belt in April 2025, and will analyse seven different Trojan asteroids between 2027 and 2033. Then, in March 2033, the Lucy mission will end. But Lucy won't stop there – it will continue its solar orbit for millions of years.

NASA first mooted Lucy in 2015, and it was formally picked as a viable mission in 2017. Its first designs were approved in 2018, and it began assembly and testing in August 2020. The final Lucy spacecraft arrived at Kennedy Space Center in Florida in July 2021 ahead of the autumn launch period.

Lucy might seem an odd name for a space mission, but it's named after a fossilised skeleton called Lucy that was discovered in Ethiopia in 1974. That fossil is 3 million years old, and it taught us a lot of new things about the evolution of humanity, so it's a fitting name for a space mission that NASA hopes will lead to similar discoveries from interstellar fossils.

**Did you know?**
Lucy is travelling at a rapid 67,000 miles per hour

The Lucy spacecraft will fly past seven Trojan asteroids and carry out remote testing with its range of advanced instruments. NASA plans to examine the geology on the surface of each asteroid to check out their age, structure and shape, and other tools will check each asteroid for minerals, ice and organic materials.

Other tools will measure the mass and density of each asteroid and will map their interior structures. NASA doesn't quite know what Lucy will find – after all, no craft has ever been there before. But the mission will supply vital information about the formation of our Solar System, and this sort of exploration is a vital part of scientific discovery.

**DID YOU KNOW?** Asteroid 52246 Donaldjohanson is named after one of the scientists who discovered the Lucy fossil in Ethiopia

### 4 EAGLE EYES

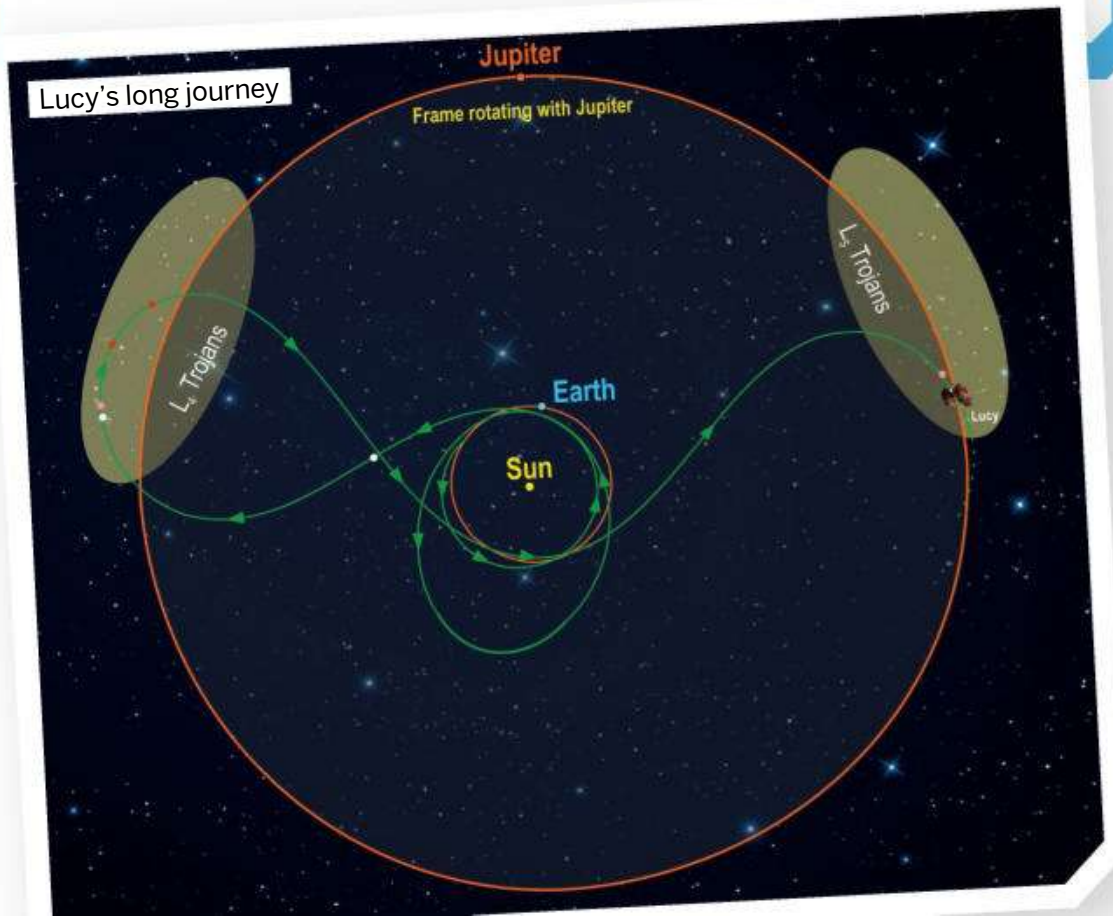
L'LORRI is Lucy's long-range camera. It'll produce black-and-white shots of each asteroid and can see 70-metre craters from 620 miles away.

AR zone

SCAN HERE

## GRAVITATIONAL PULL

**The Lucy spacecraft uses solar energy for power in deep space, but it will first orbit Earth, Mars and the Sun, relying on their gravitational pull to start its journey to the outer reaches of space. Lucy's first task is to orbit the Sun, and by October 2022 it'll hurtle back towards Earth and get a gravity-assisted boost that will speed up the spacecraft. This speed will take Lucy on a two-year orbit around Mars before it comes back to Earth in 2024 for another shot of gravitational help. It's this second shove that will propel Lucy towards the Solar System's main asteroid belt – and beyond that to the first cluster of Trojan asteroids. Once it's looped around those, Lucy will head back to Earth for its third gravitational boost, which will push the spacecraft in the opposite direction towards the second group of Trojan satellites.**



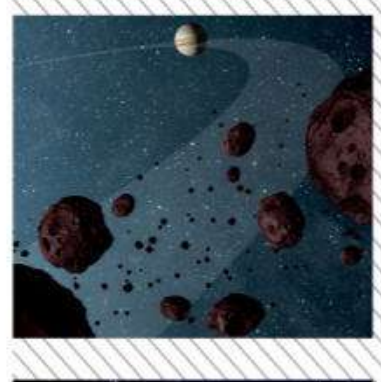

## LUCY'S TARGETS

### 52246 DONALDJOHANSON
**ESTIMATED FLYBY DATE: 20 APRIL 2025**

Lucy's smallest target is in the Solar System's main asteroid belt. NASA will use this asteroid to test Lucy's instruments.

### 3548 EURYBATES
**ESTIMATED FLYBY DATE: 12 AUGUST 2027**

This asteroid shares the same materials as some meteorites on Earth. Eurybates has its own satellite, so Lucy can study both.

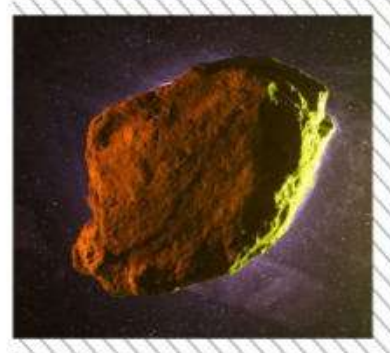


### 15094 POLYMELE
**ESTIMATED FLYBY DATE: 15 SEPTEMBER 2027**

13 miles in diameter, NASA believes that Polymele is rich in organic material – worth studying for insights into how life formed in the Solar System.

### 11351 LEUCUS
**ESTIMATED FLYBY DATE: 18 APRIL 2028**

This slow-rotating asteroid has a day that lasts for 446 hours. That slow day means it has huge temperature variations to study.



### 21900 ORUS
**ESTIMATED FLYBY DATE: 11 NOVEMBER 2028**

This asteroid is similar to Leucus. NASA hopes that tests on Orus will reveal more about organic and carbon-based materials.

### 617 PATROCLUS AND MENOETIUS
**ESTIMATED FLYBY DATE: 3 MARCH 2033**

These are thought to be left over from the early Solar System. They will provide information about how planets were formed.

© Getty / NASA;Bill Ingalls / Illustration by Adrian Mann

# Win!

## TWO XPLORA SMARTWATCHES WORTH £200

**This month we are giving you the chance to win two Xplora XGO2 smartwatches. These feature-rich devices are an ideal first mobile phone and GPS tracker for children. The XGO2 allows children to make and receive calls with presaved numbers and comes with an SOS button to notify their emergency contact of their location. These watches also count kids' steps and turn them into Xplora coins, which can be spent on the Goplay games platform**

**For your chance to win, answer the following question:**

## What year was the Hubble Space Telescope launched?

A: 1890 B: 1940 C: 1990

Enter online at **howitworksdaily.com** and one lucky entrant will win!

**Terms and Conditions:** Competition closes at 00:00 GMT on 13 January 2022. By taking part in this competition you agree to be bound by these terms and conditions and the Competition Rules: **www.futuretcs.com**. Entries must be received by 00:00 GMT on 13/01/2022. Open to all UK residents aged 18 years or over. The winner will be drawn at random from all valid entries received, and shall be notified by email or telephone. The prize is non-transferable and non-refundable. There is no cash alternative.

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OFFER EXPIRES **31 JAN 2022**

# BRAINDUMP

## Amazing answers to your curious questions

An artist's conception of a space elevator, a hypothetical alternative to launches

### MEET THE EXPERTS

Who's answering your questions this month?



**Jo Elphick**
History and forensic science



**Andy Extance**
Chemistry, tech and science



**Andrew May**
Space, transport and science



**Victoria Williams**
Animals, the environment and science

# Is there a non-rocket alternative to space launches?

**Stefan Shaffer**

In terms of present-day technology, the answer is no. Some launch systems, such as Virgin's SpaceShipTwo suborbital spaceplane, or the company's LauncherOne satellite launcher, use a conventional aircraft for the first part of the mission, but they still need a rocket to actually get into space. Nevertheless, people have speculated on alternative options that might become feasible in the future. These range from electromagnetic rail guns to enormous 'space elevators' running all the way from ground level to geosynchronous orbit. The latter would revolutionise access to space, but a whole range of engineering challenges would have to be overcome. **AM**

## CAN ANY TYPE OF FOOD HAVE NEGATIVE CALORIES?

**Angela Harding**

Negative-calorie food means that the body uses more calories to digest it than can be found in the food itself. The higher the water content, the closer a food gets to having negative calories. Unfortunately, there's no evidence to suggest that such a food actually exists... not even celery. **JE**

## HOW DOES WHATSAPP MAKE MONEY?

**Jeremy Saunders**

Until 2016, Whatsapp made money through a $1 (£0.76) subscription. Today its revenue may come from selling software and services to businesses, but Whatsapp hasn't shared its strategies with the general public. **JE**

## Can all animals get cancer?

**Petra Lambert**

Most molluscs, fish, reptiles, birds and mammals can. Certain animals, like whales, elephants and naked mole-rats have evolved resistance to cancer and rarely seem to be affected. **VW**

**Did you know?**

The Tasmanian devil can develop contagious cancers

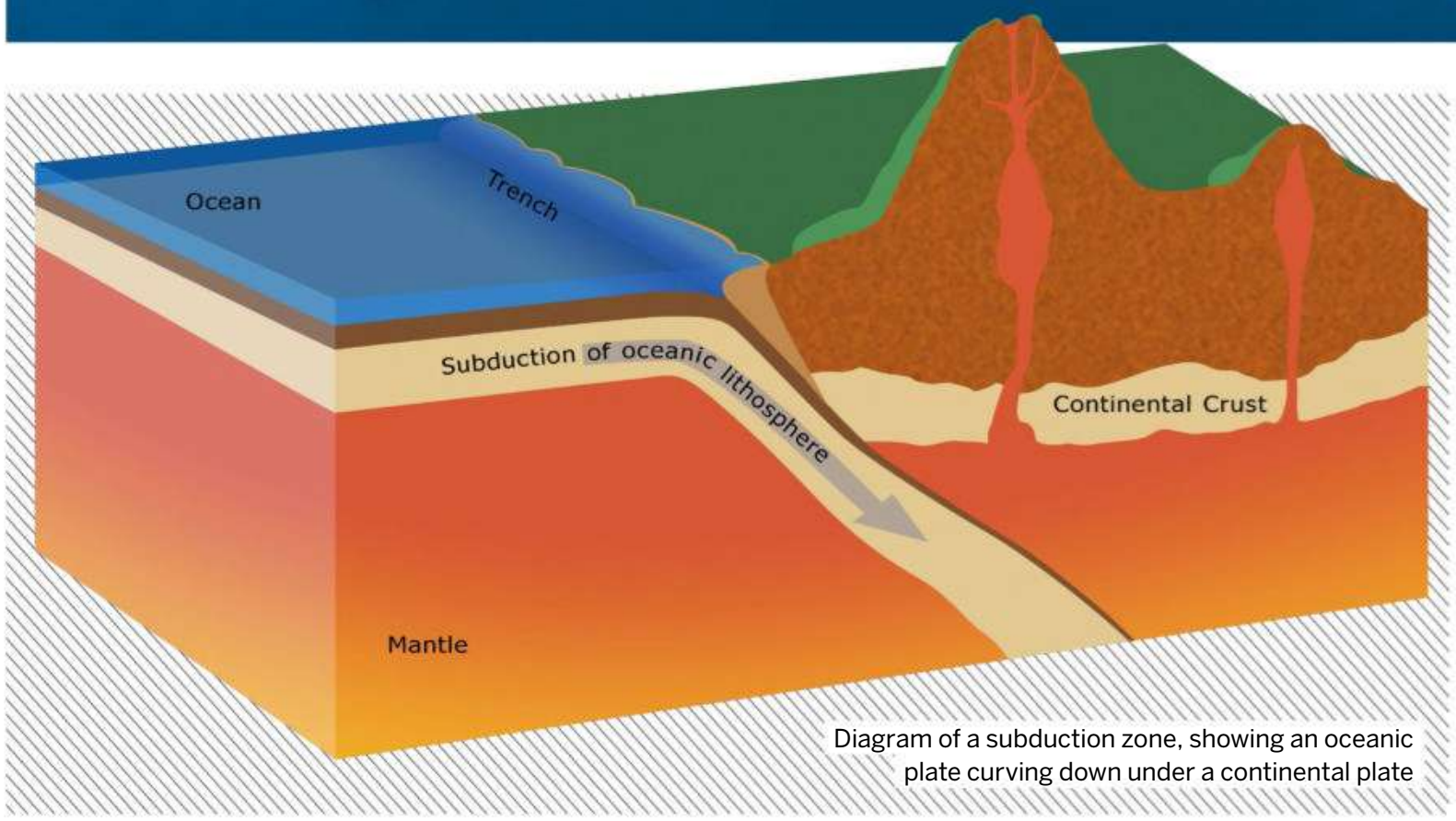



Diagram of a subduction zone, showing an oceanic plate curving down under a continental plate

# What happens to the land that slides under another tectonic plate?

**Adele Serrano**

Earth's crust, making up the continental landmasses and ocean floors, is split into a number of tectonic plates which move relative to each other on very slow geological timescales. Sometimes one plate can slide under another in a process called subduction. This most commonly happens to oceanic plates, which are the denser kind. The subducted plate ends up curving down into the Earth's mantle – the hot layer immediately below the crust. **AM**

© Alamy / Getty

# BRAINDUMP

## WHAT ARE BLOOD TYPES?

**Fahad Garrison**

Blood types, or blood groups, identify the different antibodies and antigens found in human blood. There are four main types based on the ABO group system: A, B, AB and O. Each has a different combination of 'A' and 'B' antigens on the surface of the red blood cells and 'anti-A' and 'anti-B' antibodies in the plasma. If an extra antigen known as the RhD antigen is present, the blood type is RhD positive; if not, it's negative. That gives eight blood types in total. The antigens and antibodies in your blood, and therefore your blood type, are determined by the DNA you inherited from your parents. **VW**

If a patient is given the wrong blood, their immune system can reject and attack it

The purple Persian shield plant is green along its veins, but the rest of its leaves are a striking purple colour

## Why are some plants' leaves purple?

**@scimaxfacts**

A plant might have purple leaves for a number of reasons. The leaves might be rich in anthocyanin, a pigment that absorbs green and yellow light, making them appear reddish or purple. These plants still contain chlorophyll – otherwise they couldn't produce energy from sunlight using photosynthesis – but the anthocyanin masks the green colouring. When a plant that normally has green leaves turns purple, it's usually because of a phosphorus deficiency. **BB**

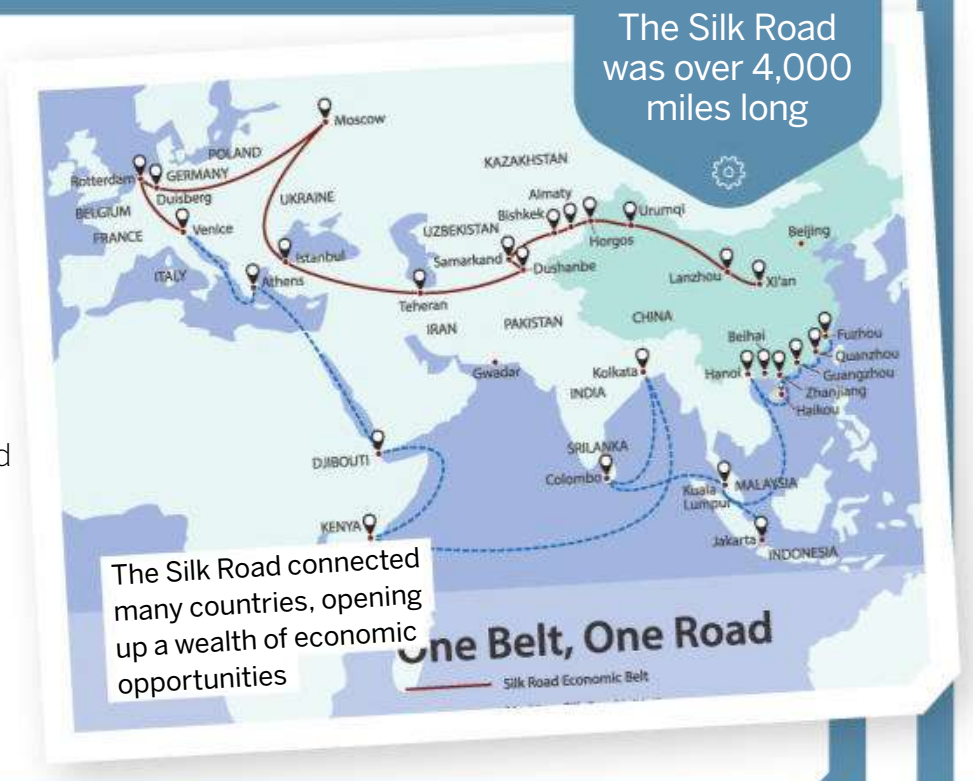
**Did you know?**

The Silk Road was over 4,000 miles long

## DID THE SILK ROAD START IN CHINA OR EUROPE?

**Max Rader**

It's thought that the series of trade routes commonly known as the Silk Road started in Xi'an in China, following the Great Wall until it circumnavigated the Taklamakan Desert, climbed China's Pamir Mountains and travelled across Afghanistan. From there it headed towards Levant before crossing the Mediterranean Sea and reaching Eastern Europe. Silk, gunpowder, rice and exotic perfumes were transported from China to Europe, while fruit, honey, animals and textiles travelled from Europe to China. **JE**



The Silk Road connected many countries, opening up a wealth of economic opportunities

## TOMATOES ARE PART OF THE NIGHTSHADE FAMILY. DOES THAT MEAN THEY'RE A BIT POISONOUS?

**Jaiden Corbett**

Edible members of the Solanaceae family – including tomatoes, bell peppers and potatoes – do produce toxic chemicals, like the alkaloid solanine, but only in harmless quantities. Tomatoes have a slightly higher toxicity when they're green, so while it's unlikely to be deadly, eating loads of green tomatoes might make you sick. **VW**

## HOW DO HUGE METAL SHIPS FLOAT ON WATER?

**Oscar Shepherd**

Ships are filled with air, making them buoyant. Across the entire size of a ship, its density is less than water. Less dense objects float on more dense liquids. **AE**

Keeping warming below 1.5 degrees Celsius could halve sea level rise from melting polar ice

# Why is a global temperature rise of just a few degrees so bad for the planet?

**Taya Hulme**

When scientists talk about the effects of a few degrees of warming, they're talking about the average temperature increase around the planet. But warming doesn't happen equally; some areas, like the poles and the equator, are seeing temperatures rise much faster. Earth and its ecosystems are extremely delicate, sensitive to the slightest changes. A global rise of 1.5 degrees Celsius is enough to irreversibly alter these natural systems, impacting everything from the weather to animal habitats. **VW**

© Allamy / Getty

# Why do bubbles pop in the air?

**Suraj Lancaster**

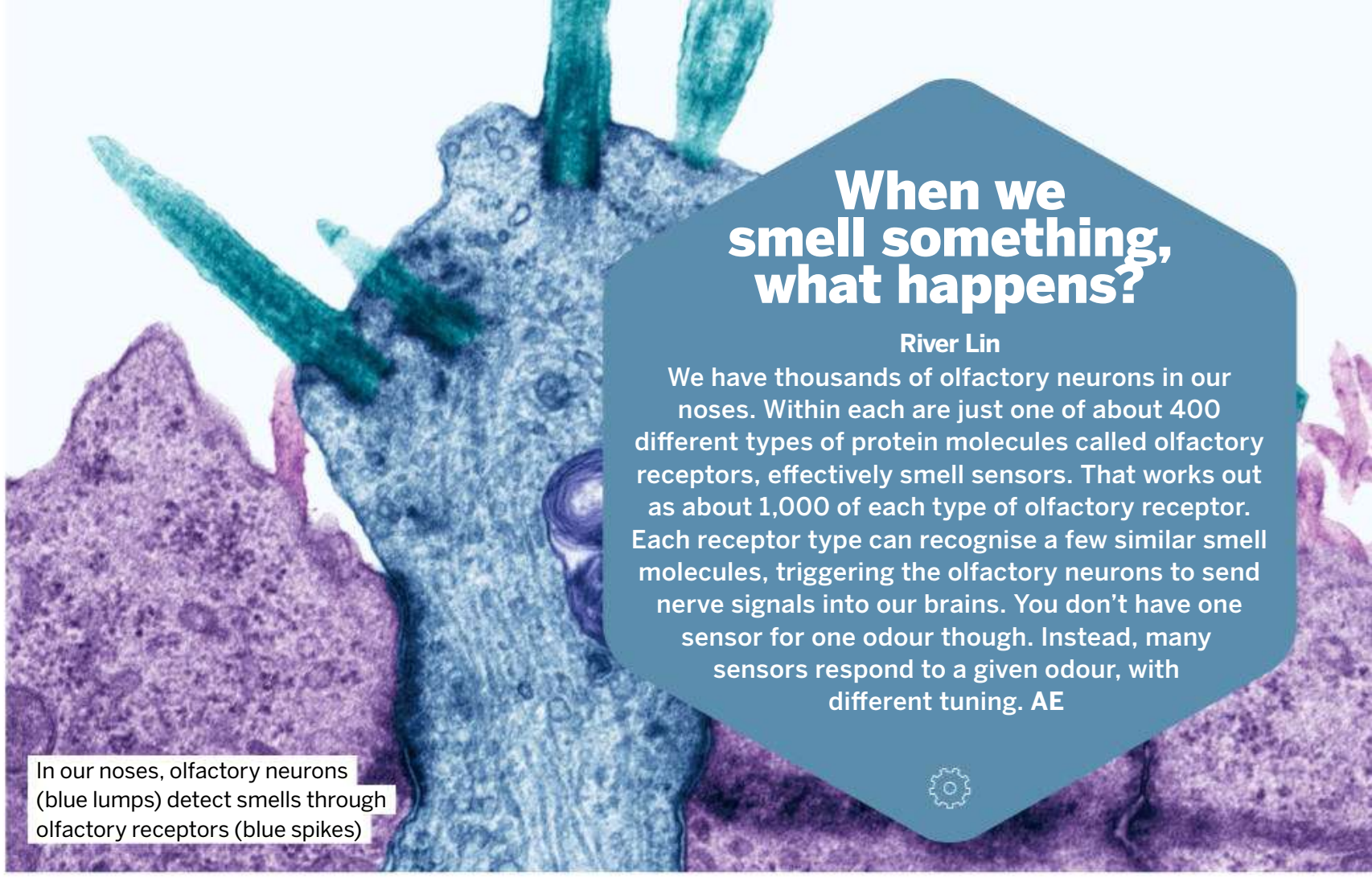
The outer surface of a bubble is a liquid like soapy water. Molecules in the water squeeze together. This force, called surface tension, traps a gas like air inside. But the water gradually disappears into the outside air, like a puddle drying out. That weakens the bubble, and it pops. **AE**

## WHAT IS THE BIGGEST EMPIRE THAT EVER EXISTED?

**Poppy Hastings**

It really depends on what you are basing your empire on. If you consider area then the British Empire would be the biggest, since it conquered more areas of the world than anyone else. At its height it covered a quarter of the globe. That's 13.7 million square miles, making the saying 'the Sun never sets on the British Empire' absolutely true. By 1920 it also included one-quarter of the world's population. However, if you consider an empire in terms of longevity then the Roman Empire wins, since it ruled for over 1,500 years. **JE**

King George V was ruler of the British Empire in 1920



In our noses, olfactory neurons (blue lumps) detect smells through olfactory receptors (blue spikes)

## When we smell something, what happens?

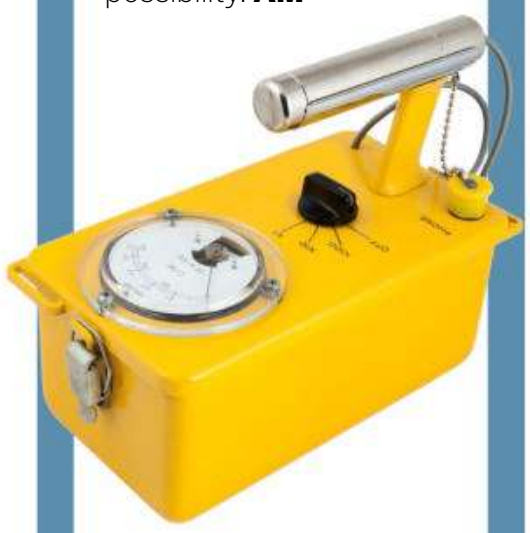
**River Lin**

We have thousands of olfactory neurons in our noses. Within each are just one of about 400 different types of protein molecules called olfactory receptors, effectively smell sensors. That works out as about 1,000 of each type of olfactory receptor. Each receptor type can recognise a few similar smell molecules, triggering the olfactory neurons to send nerve signals into our brains. You don't have one sensor for one odour though. Instead, many sensors respond to a given odour, with different tuning. **AE**

## ARE THERE ANTIMATTER STARS?

**Vanessa Wilde**

We don't know of any, but astronomers haven't ruled out their existence, even here in our own Milky Way. Although antimatter and ordinary matter annihilate each other when they come into contact, an isolated star made entirely of antimatter is a theoretical possibility. **AM**



## HOW DOES A GEIGER COUNTER WORK?

**Lucas Fenton**

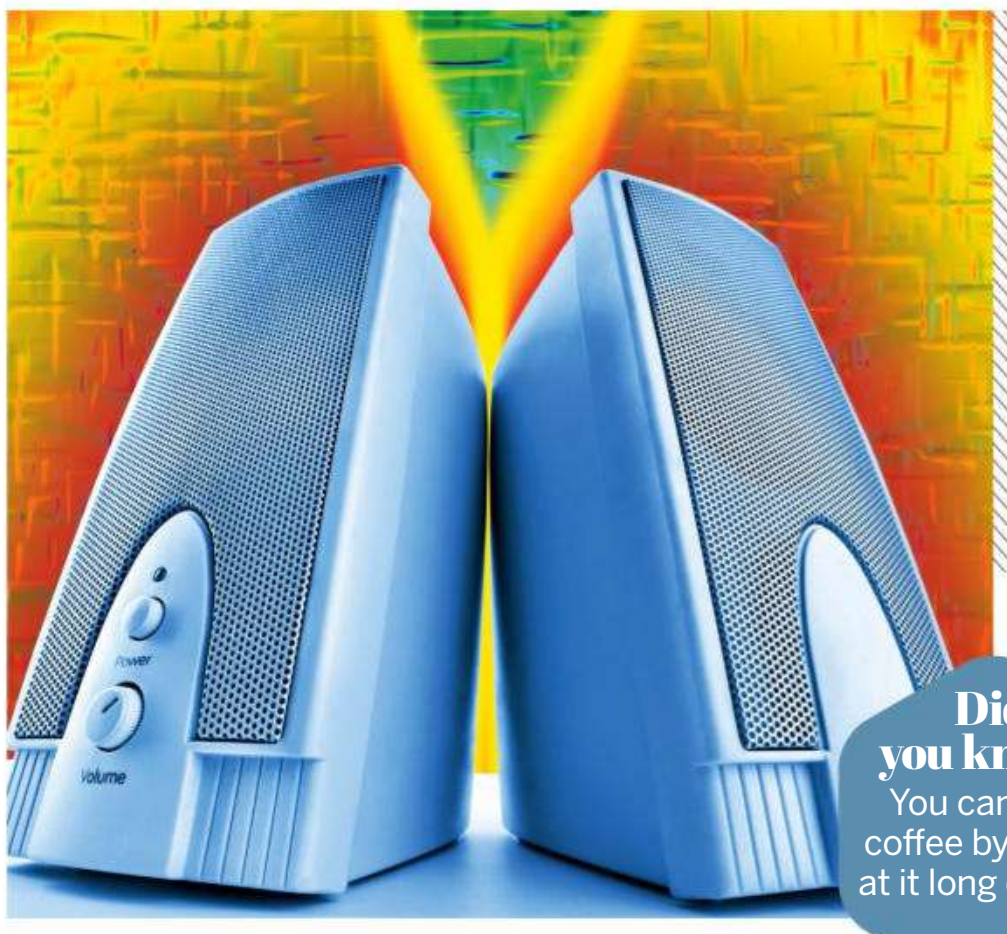
Geiger counters detect radioactivity. They are usually tubes filled with gas atoms, connected into an electrical circuit. Radioactivity can pass through the tube and hit the atoms. The atoms fall apart, splitting into parts with opposite electrical charge. When that happens, an electrical pulse moves through the circuit. **AE**

## WHY DO YOU NEED LESS SLEEP THE OLDER YOU GET?

**Han Ruoguang**

Through your childhood, you need more sleep than adults as your body and brain are growing and developing. Essential hormones are released to regulate this growth while you sleep. During your teenage years, your body needs more sleep as it changes during puberty. Adults produce less of the sleep hormone melatonin, which can reduce the likelihood of deep sleeps and cause shorter sleeps. Insomnia in retirees is fairly common, where it's thought that the ageing process disrupts your circadian rhythm – your physical and mental cycle over a 24-hour period – causing you to wake earlier. **BB**

Older adults can suffer more from health conditions that disrupt their sleep




## Can sound generate heat like light?

**Sebastian Gardner**

Yes. A sound wave is the coherent motion of air molecules, but as it travels this coherent motion gradually becomes randomised, and random motion is a form of heat. **AM**

**Did you know?**
You can heat coffee by yelling at it long enough

© Alamy / Getty / ESA/Hubble

# THE LIBRARY

The latest book releases for curious minds

## NATURE'S TREASURES

### 100 NATURAL OBJECTS WITH AMAZING TALES TO TELL

AUTHOR **BEN HOARE**
ILLUSTRATOR **KALEY MCKEAN**
PUBLISHER **DK CHILDREN**
PRICE **£20 / $24.99**
RELEASE **OUT NOW**

**"Nature always has something interesting and unknown for us to discover"**

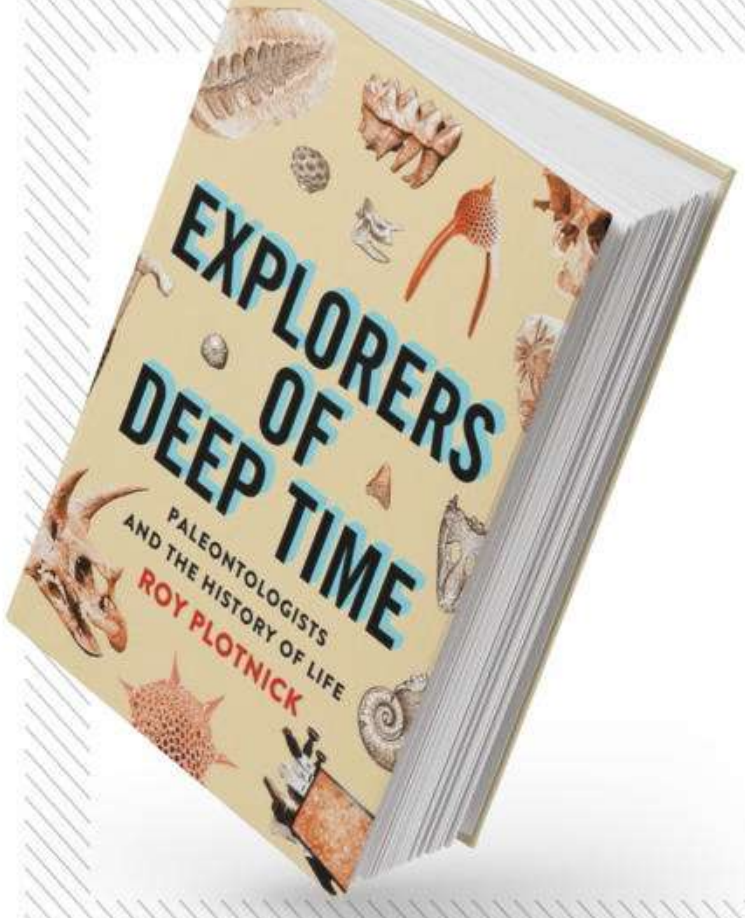
How many times have you been down to the seashore and picked through the flotsam and jetsam at the tideline? Or foraged through the undergrowth in the woods, or sifted through the pebbles at a cliff face? What did you find and what did you think about it?

Perhaps there was a mermaid's purse, the skull of an unidentified animal, a sparkling geode, a fossil or a strange seed casing. Nature always has something interesting and unknown for us to discover, even as adults in an environment that we're intimately familiar with, and best-selling nature writer Ben Hoare knows this. Here he has compiled a selection of his favourite natural treasures into this attractive, gilt-edged hardback.

These 100 choice objects are evenly split into four main categories: animals, plants, minerals and 'made by nature' – eggs, nests and even animal excreta. Owl pellets and dung beetle balls have incredibly fascinating tales to tell as long as you can get over the fact that they're little balls of sick and poop respectively. And that's what *Nature's Treasures* is really about – it's not a spotter's guide to what can be found in nature, but the broader tales of where these objects came from, how they came to be, their place in the world and their impact on humanity.

It explores things like pyrite, also known as fool's gold, a brittle but shiny, yellow mineral that has probably hoodwinked thousands of people over the years into thinking they've hit the jackpot. It gives off sparks when struck and gave our ancient ancestors a means of starting fires. Maybe a more common treasure for some to find would be the empty chrysalis of a butterfly – if you can pick them out of the surroundings that they're camouflaged among. Adult butterflies often look radically different to their caterpillar larvae before they spin their chitinous casing around themselves. A chrysalis will twitch if touched while the caterpillar is still inside, and some will even squeak.

*Nature's Treasures* is very much a natural guide intended to inspire a younger audience to keep eyes open and their curiosity sharpened while they're out and about, though there's plenty for adults to learn from it, too.




## EXPLORERS OF DEEP TIME

### PALAEONTOLOGISTS AND THE HISTORY OF LIFE

AUTHOR **ROY PLOTNICK**
PUBLISHER **COLUMBIA UNIVERSITY PRESS**
PRICE **£30 / $35**
RELEASE **4 JANUARY**

Delve deep into the world of palaeontology with this insightful and revealing book. Professor of palaeontology Roy Plotnick takes the reader on a behind-the-scenes tour of the life of a palaeontologist and how they explore the history of life on Earth. Plotnick unveils the misconceptions about the discovery of ancient life and breaks the stereotypes of those that study it. This book is filled with stories of the author's career and experiences in the field, as well as a whole host of tales from his colleagues. The biographical tone of the book not only reveals Plotnick's past but unearths the history of the profession as a whole.

If you're looking to pursue a career in the area of palaeontology or if you're about to embark on a university degree in the same field, this book is an excellent source of information and an enjoyable read.

# NANO'S JOURNEY!

## A LITTLE STEM CELL VISITS THE HEART AND LUNGS

AUTHOR **ALDO POURCHET**
ILLUSTRATOR **JEN YOON**
PUBLISHER **PIXEL MOUSE HOUSE**
PRICE **£9.41 / $12.99**
RELEASE **OUT NOW**

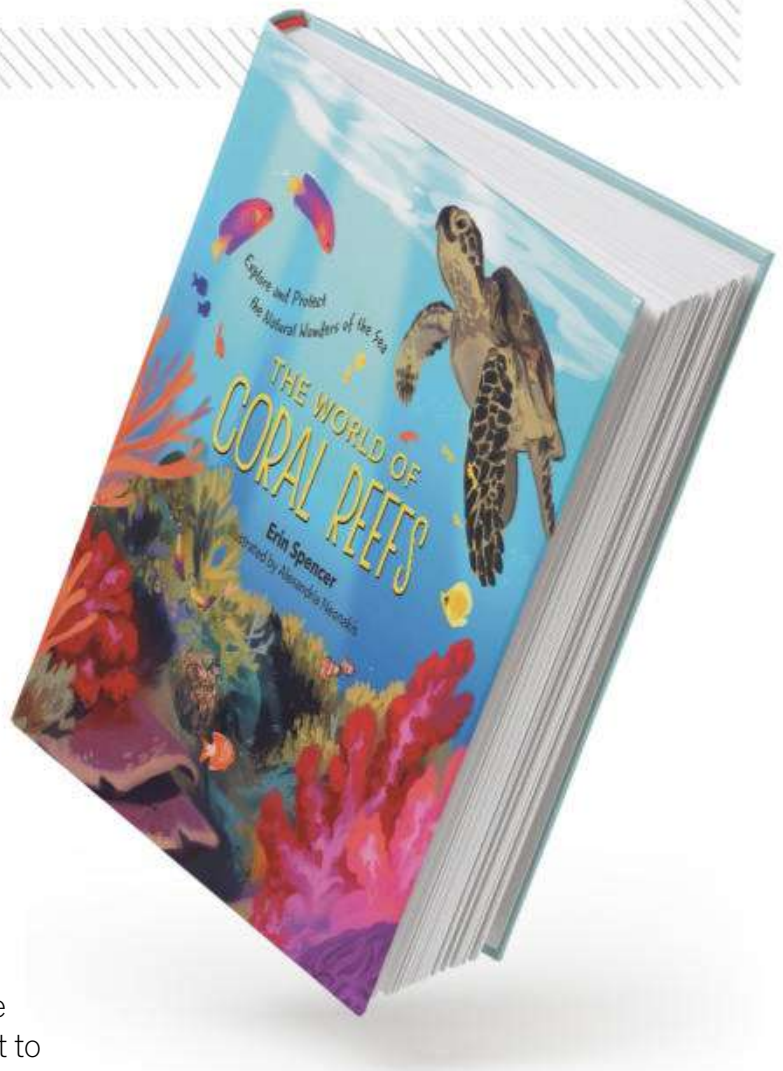
Join Nano the stem cell and Blasto the fibroblast cell as they journey through the human bloodstream to the heart and lungs. As a stem cell, Nano can transform into any different type of cell, so she sets off on a journey to discover which type of cell she should become. In this book, Nano explores the role of red blood cells and how they supply our hearts and lungs with the vital oxygen needed to survive.

This book is a great tool to introduce a child to the function of the circulatory system and the role stem cells play in the human body and is best suited for two to five year olds. Along with the fun narrative and vibrant illustrations, there's an informative appendix for a deeper understanding of some of the cells and organs Nano meets. This book is the first in a series that will see Nano explore different parts of the human body.

# THE WORLD OF CORAL REEFS

## EXPLORE AND PROTECT THE NATURAL WONDERS OF THE SEA

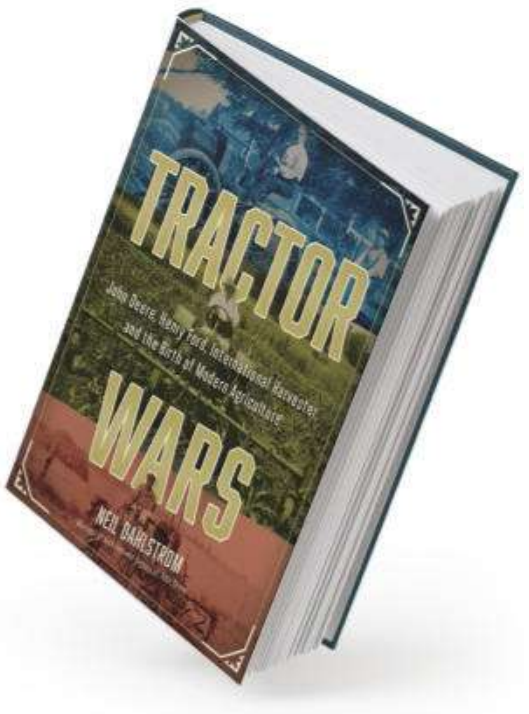
AUTHOR **ERIN SPENCER**
ILLUSTRATOR **ALEXANDRIA NEONAKIS**
PUBLISHER **STOREY PUBLISHING**
PRICE **£11.92 / $16.95**
RELEASE **29 MARCH 2022**




Did you know that coral reefs cover less than one per cent of the ocean floor, but around a quarter of ocean life depends on them? In *The World of Coral Reefs* your mind is transported to the marine life of the reef. From the coral that bathes in sunlight to the deep-sea coral discovered in the darker depths, this book includes extensive information about these diverse ecosystems.

A large part of *The World of Coral Reefs* focuses on the impact coral has on other animals, from the large dugongs that use it for a much needed meal to the clownfish that capture prey in their stinging anemone homes. Author Erin Spencer explains the interesting ways that coral helps humans, like by protecting us from dangerous storms and helping us to treat diseases. Vitally, this book includes ways that we can help return the favour and look after the reefs. Throughout the book Spencer details noteworthy facts, while the illustrations turn detailed scientific diagrams into engaging artwork – including the coral life cycle and cellular anatomy.

After learning all about this ecosystem, readers may want to see how they can conserve coral reefs, see impressive photographs or view underwater scenes on Google Earth. Links and resources like these are found in the last pages so that this book can be the beginning of the reader's exploration.




# TRACTOR WARS

## JOHN DEERE, HENRY FORD AND THE BIRTH OF MODERN AGRICULTURE

AUTHOR **NEIL DAHLSTROM**
PUBLISHER **MATT HOLT**
PRICE **£18.75 / $25.00**
RELEASE **18 JANUARY 2022**

When the first tractors were invented, farming was radically transformed. No longer was the intense labour of people required to plow fields, or the power of horses needed to get from A to B. But tractors didn't simply appear overnight. A battle took place between Ford, John Deere and International Harvester. This book is an in-depth account of the events that gave rise to power farming. Author Neil Dahlstrom has carried out thorough research to tell the real stories of those involved in the tractor's production and development.

Written to draw the reader into this story from the first chapter, the true events of farming's evolution begin with the characters. Instead of just another list of this technology's key advancements, the book digs further to explain the reasons behind these pivotal moments and the personal conversations that took place. What sparked Henry Ford's passion to contribute to farming technology? And how did he clash with International Harvester's president Alexander Legge? *Tractor Wars* is an ideal book for farming and tractor enthusiasts who want to explore the little-known details about the design, engineering and history of the vehicle fit to feed a growing population.

# BRAIN GYM

Give your brain a puzzle workout

## Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

**EASY**

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**MEDIUM**

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**HARD**

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| | | 2 | 9 | | | 1 | | 7 |
| 2 | | | | 3 | | | | |
| | | 9 | | | | 8 | 2 | 4 |
| | | | | 8 | 2 | | | 6 |

## Word search

Find the following words

LASER
FACILITY
COLOUR
DESERT
LANGUAGE
DISASTER
CARGO
GOLD
QUANTUM
HEATER
WATER
CUCKOO

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Q | E | S | E | A | R | T | D | G | O | L | F | I | E | H |
| U | F | A | C | I | L | I | T | Y | C | U | K | O | O | E |
| A | D | R | I | U | Q | A | C | O | L | U | Q | D | X | A |
| L | O | U | R | D | B | F | H | E | A | R | E | I | O | T |
| I | Y | C | O | L | O | U | R | G | D | O | Z | S | O | E |
| T | R | E | W | A | G | D | I | S | M | O | V | A | C | R |
| O | S | C | U | S | A | O | T | U | B | K | M | S | E | Q |
| M | I | N | S | E | L | I | T | Y | U | C | K | T | P | Y |
| T | E | C | Q | R | O | N | V | A | R | U | N | E | F | I |
| R | A | P | I | L | A | J | E | B | U | C | A | R | G | O |
| E | U | D | E | U | S | E | D | R | W | A | E | M | A | D |
| S | J | O | Q | E | X | L | I | C | R | E | T | A | W | U |
| E | O | R | N | C | O | L | A | G | O | L | N | A | K | O |
| D | E | T | F | G | I | J | V | U | W | T | O | I | M | A |
| I | L | I | U | H | D | A | E | G | A | U | G | N | A | L |

## What is it?

Hint: With magnification, no two of these crystals are exactly alike

A

# Spot the difference

See if you can find all six changes between the images below

# Answers

Find the solutions to last issue's puzzle pages

**Q1** METHANE
**Q2** CAT'S EYES
**Q3** DEFENCE AGAINST INSECTS
**Q4** D-WAVE ADVANTAGE
**Q5** HEAT
**Q6** 1.3 MILLION

## What is it?

BIG BEN

## Spot the difference

# QUICKFIRE QUESTIONS

**Q1 What were the first flying animals?**

- Pterosaurs
- Dragonflies
- Archaeopteryx
- Bats

**Q2 Which of these Solar System worlds has the most liquid water by volume?**

- Europa
- Earth
- Pluto
- Ganymede

**Q3 What is crude oil made of?**

- Ancient, decayed trees
- Tiny fossilised creatures
- Rocks under huge pressure
- Deep fat fryer leftovers

**Q4 How many bytes of information are in a petabyte?**

- 1 billion
- 1 million
- 1 trillion
- 1 quadrillion

**Q5 Why are sloths so slow?**

- They have a low metabolism
- The leaves they eat contain chemicals that drug them
- They're very lazy
- They're not slow, we're fast

**Q6 What is the antimatter equivalent of an electron?**

- Positron
- Neutron
- Quark
- Tachyon

© Alamy / Getty

# HOW TO...

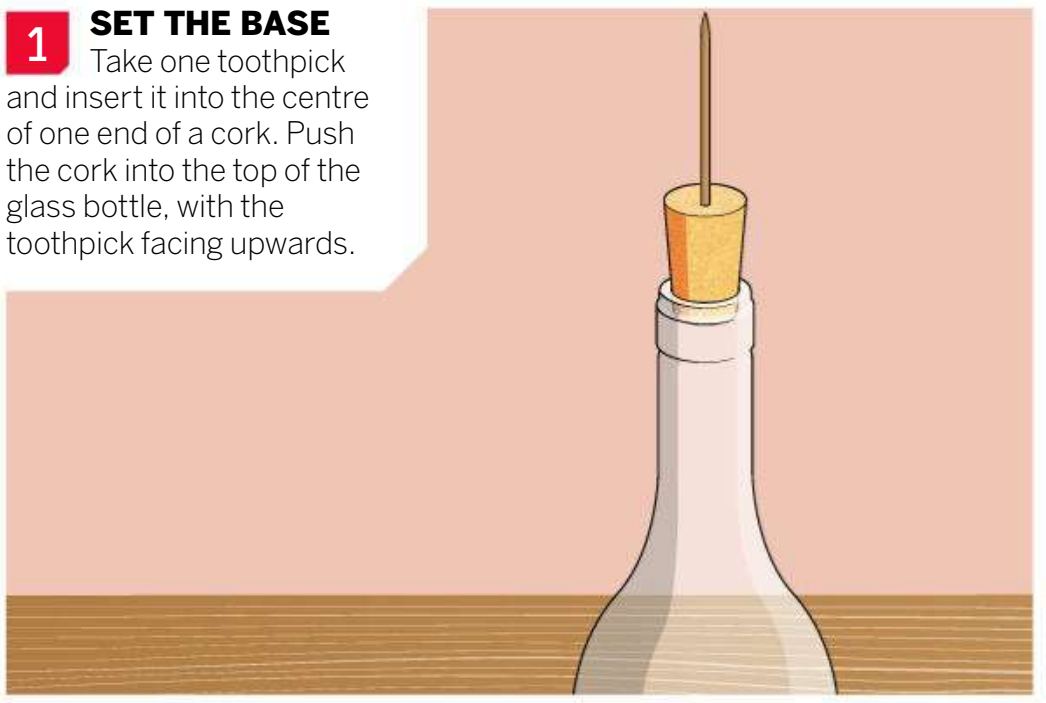
Practical projects to try at home

**KIT LIST**

- Glass bottle
- Five bottle corks
- Six toothpicks
- Two forks
- Matches

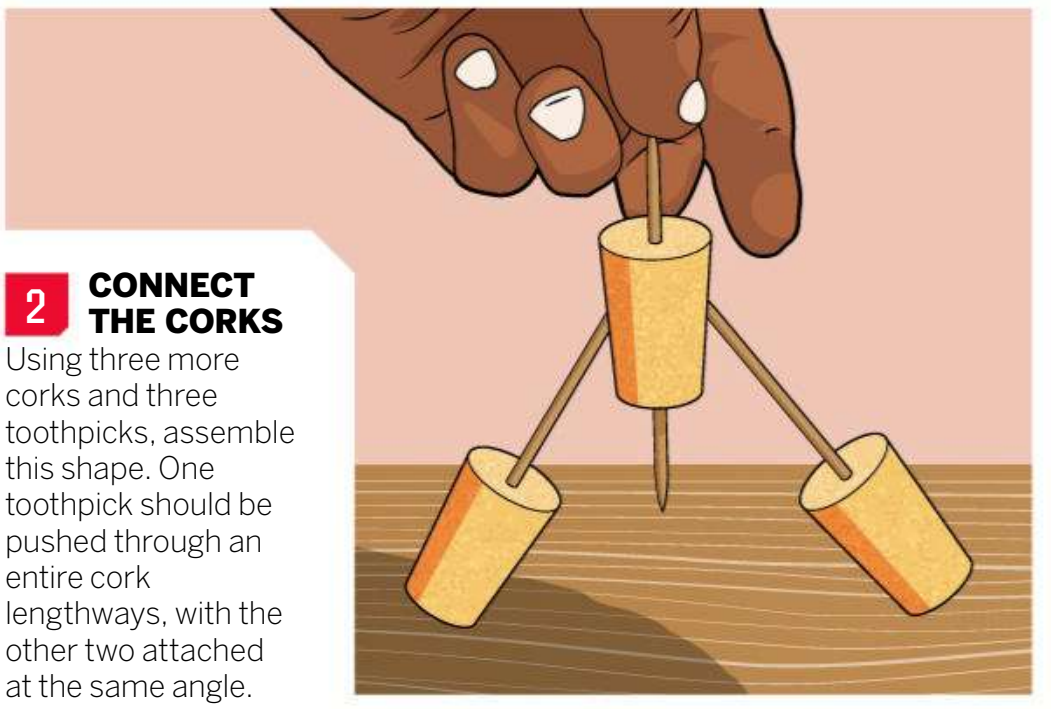
# DEFY GRAVITY WITH FORKS

What keeps this contraption suspended on a toothpick?



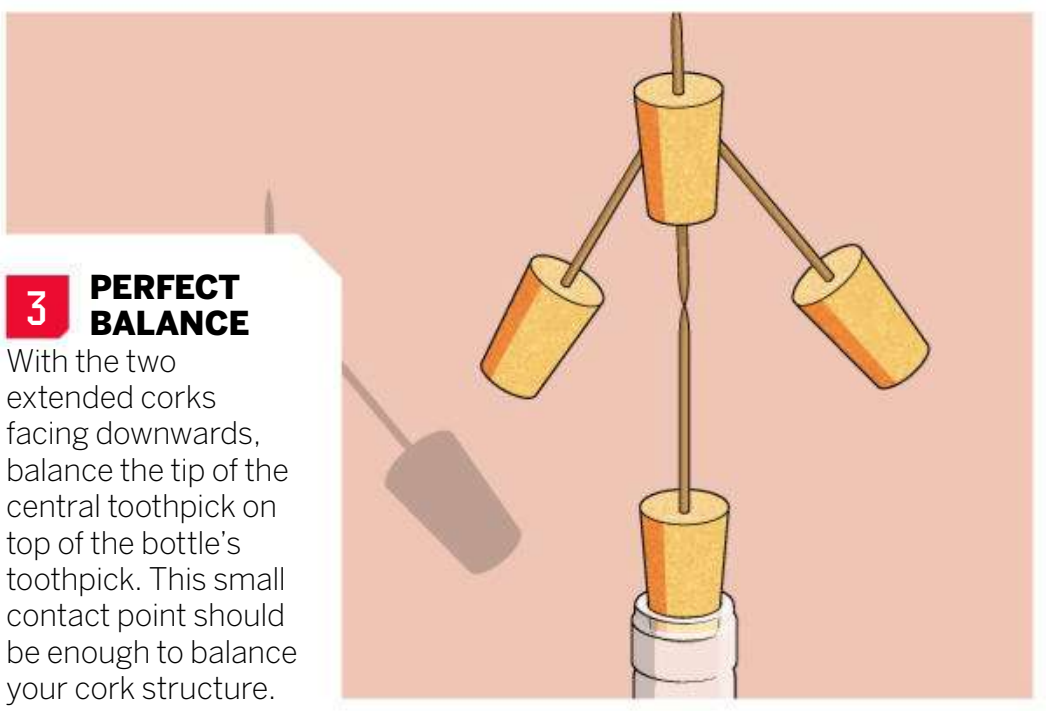
## 1 SET THE BASE

Take one toothpick and insert it into the centre of one end of a cork. Push the cork into the top of the glass bottle, with the toothpick facing upwards.



## 2 CONNECT THE CORKS

Using three more corks and three toothpicks, assemble this shape. One toothpick should be pushed through an entire cork lengthways, with the other two attached at the same angle.

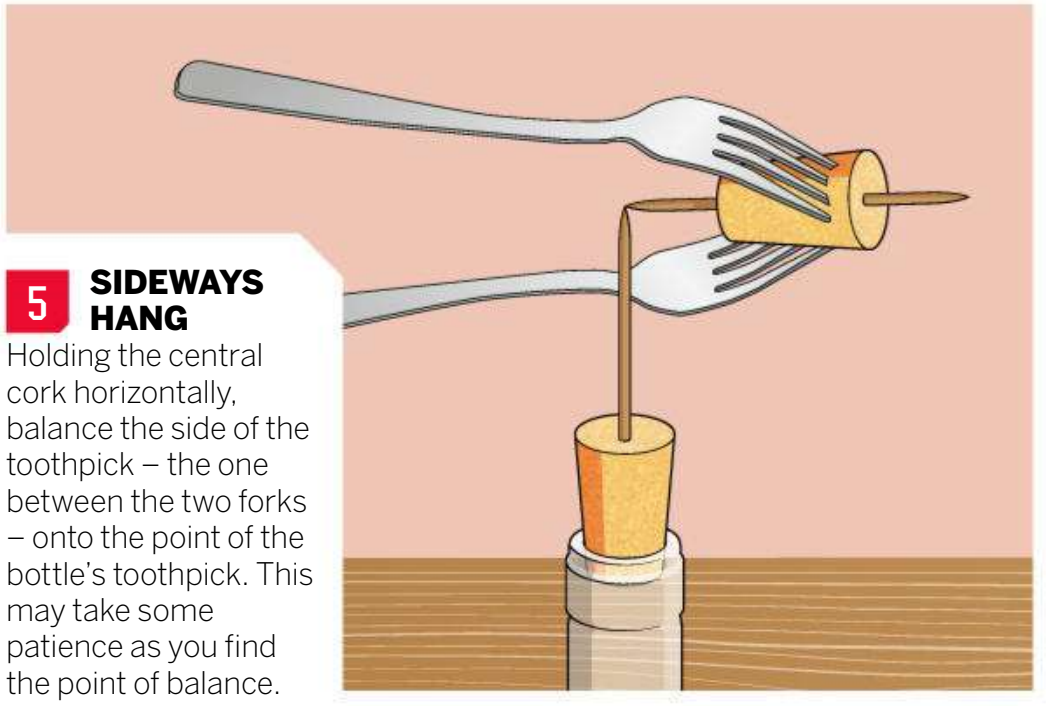


## 3 PERFECT BALANCE

With the two extended corks facing downwards, balance the tip of the central toothpick on top of the bottle's toothpick. This small contact point should be enough to balance your cork structure.

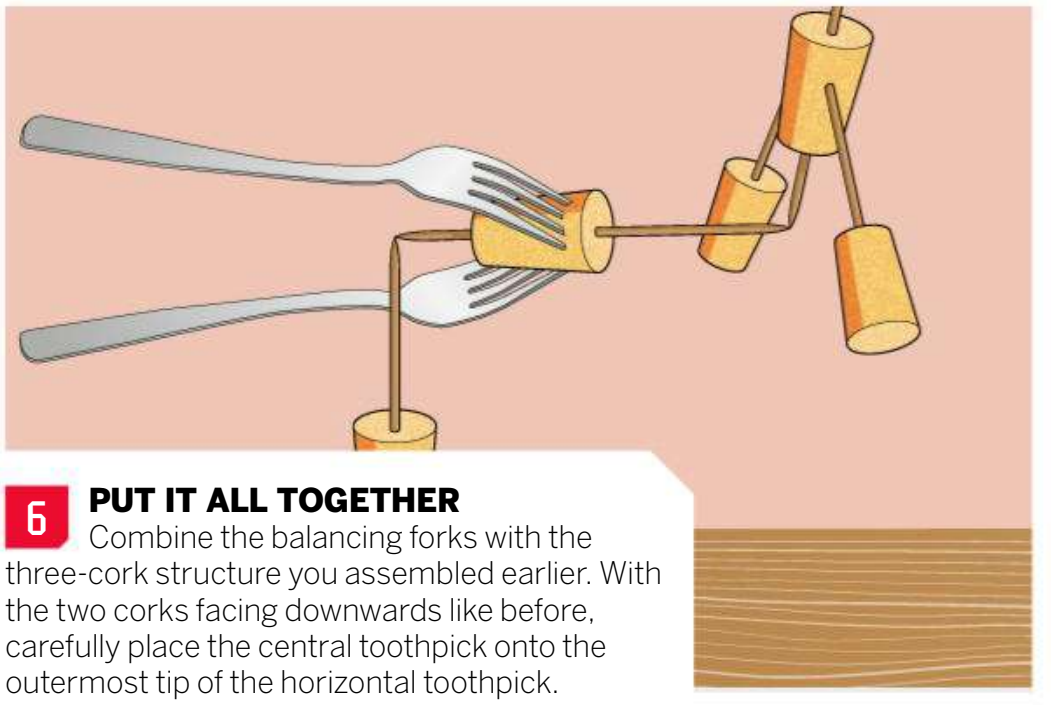
## 4 A MORE IMPRESSIVE STUNT WITH FORKS

Take off the balancing section and place it to one side. Poke the remaining two toothpicks into the centre of one cork lengthways so that they stick out evenly. At the same angle that the two corks were positioned, insert the forks firmly into the central cork.



## 5 SIDEWAYS HANG

Holding the central cork horizontally, balance the side of the toothpick – the one between the two forks – onto the point of the bottle's toothpick. This may take some patience as you find the point of balance.



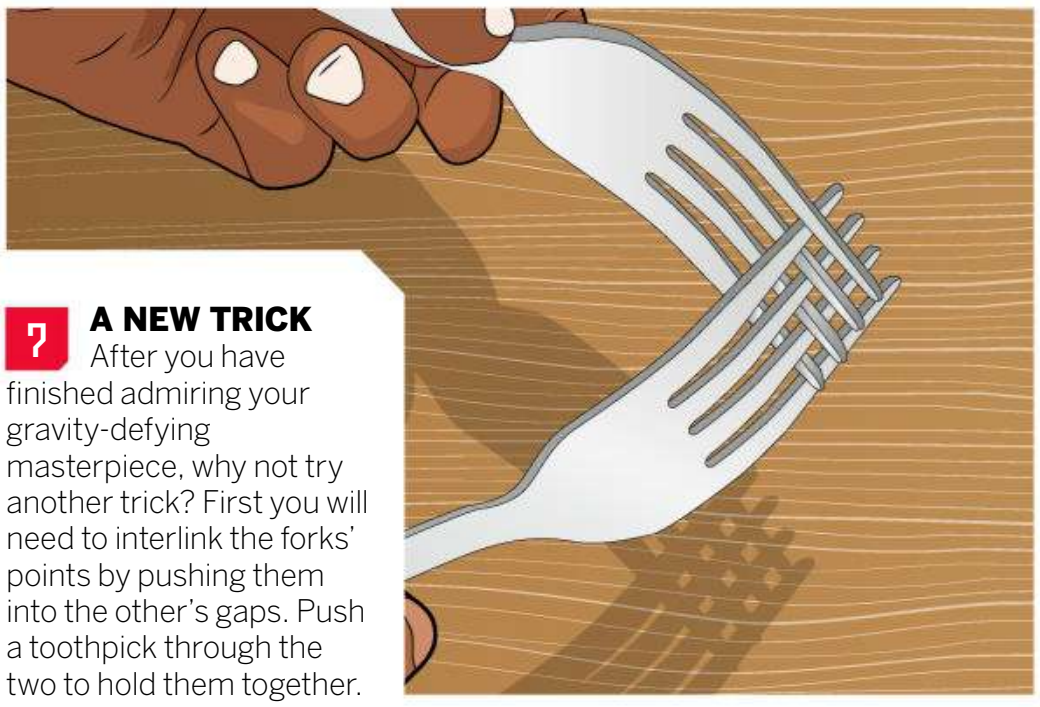
## 6 PUT IT ALL TOGETHER

Combine the balancing forks with the three-cork structure you assembled earlier. With the two corks facing downwards like before, carefully place the central toothpick onto the outermost tip of the horizontal toothpick.

NEXT ISSUE
HOW TO GROW YOUR OWN STALACTITE

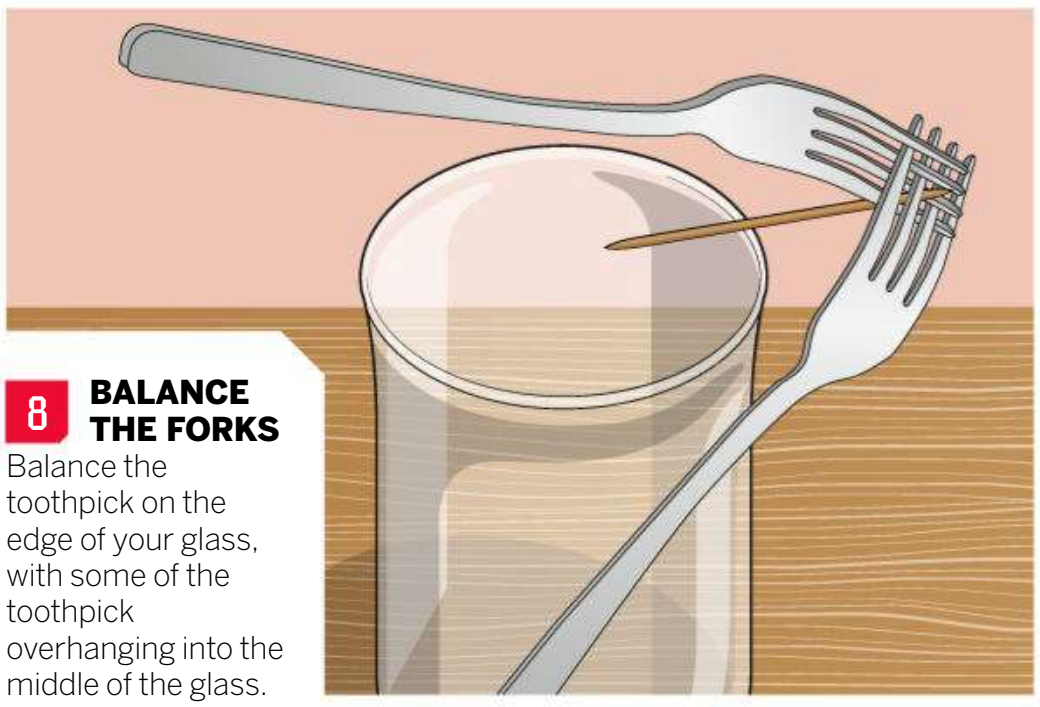
## DON'T DO IT ALONE!

If you're under 16, make sure you have an adult with you



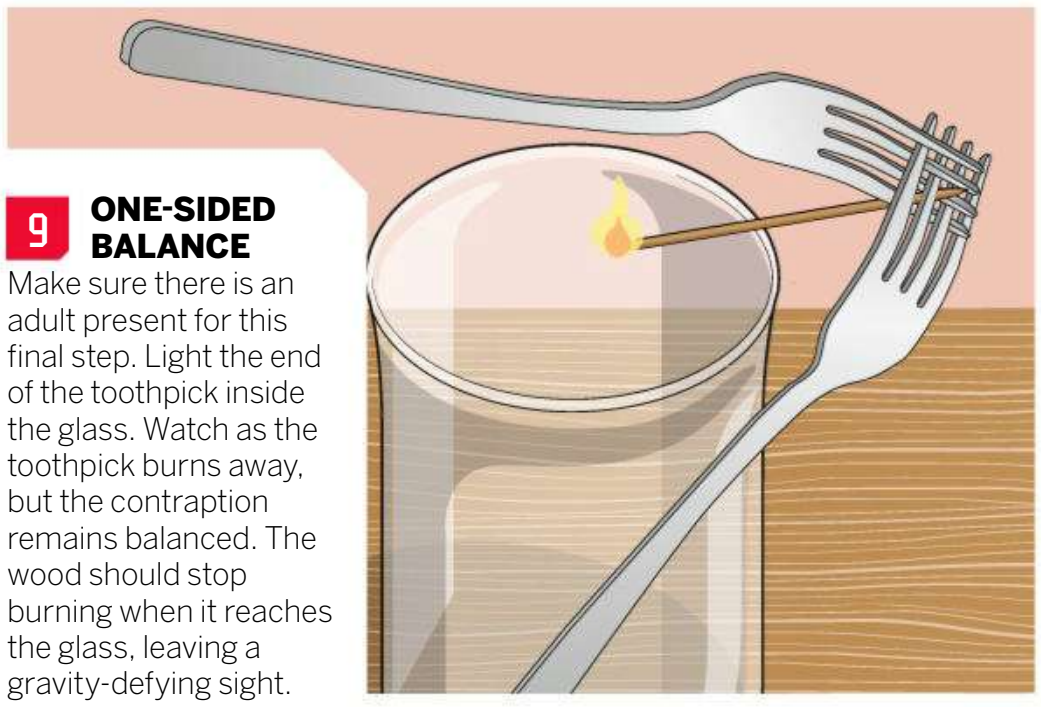
### 7 A NEW TRICK

After you have finished admiring your gravity-defying masterpiece, why not try another trick? First you will need to interlink the forks' points by pushing them into the other's gaps. Push a toothpick through the two to hold them together.



### 8 BALANCE THE FORKS

Balance the toothpick on the edge of your glass, with some of the toothpick overhanging into the middle of the glass.



### 9 ONE-SIDED BALANCE

Make sure there is an adult present for this final step. Light the end of the toothpick inside the glass. Watch as the toothpick burns away, but the contraption remains balanced. The wood should stop burning when it reaches the glass, leaving a gravity-defying sight.

### SUMMARY

**In this experiment, the centre of mass is directly below the point where the toothpick balances. The centre of mass is the point where all mass from the structure is concentrated. When the forks are wedged together, their heavy handles extend towards the opposite side of the toothpick, away from where they make contact with the toothpick. Their position in the air helps to move the centre of mass away from this point to where the toothpick is balanced.**

**When the toothpick is burning away in the second part of the experiment, the centre of mass does change, but only by a small amount. Because the forks have a much greater mass, losing a small percentage of the entire structure's mass means that its centre only shifts slightly towards the forks. This distance is smaller than the rim of the glass, and so the structure remains balanced. The flame goes out when it reaches the glass as it loses its heat.**

## Had a go? Let us know!

If you've tried out any of our experiments – or conducted some of your own – let us know! Share your photos or videos with us on social media.

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# INBOX
Speak your mind

## WIN!
AN AMAZING PRIZE FOR LETTER OF THE MONTH

**MEET THE OCEANS**

Get ready to explore all of Earth's oceans, from the deep Pacific to the sparkling Mediterranean, in this striking, story-led picture book.

## LETTER of the MONTH

# ORBITING JUNK

Dear **HIW**,
As there's so much space debris, why aren't spacecraft hit by something and disabled? It seems there would be a high chance of this, but in practice it doesn't seem to happen!
**Stephen Conn**

Debris accumulates as space exploration continues

**There are over 27,000 pieces of space junk being monitored. To prevent collisions, the Department of Defense tracks them via numerous sensors that make up the Space Surveillance Network. Space debris can be both artificial and natural. The latter orbits the Sun, while human-made debris usually orbits Earth. This includes nonfunctional spacecraft and stages from launch vehicles. Space junk can travel at 17,500 miles per hour, so even relatively small fragments can cause significant damage. To protect the International Space Station (ISS) and the crew on board, flight rules are put in place. These state how close a piece of tracked space junk can be from the ISS before the chance of collision is high enough to warrant evacuation.**

**The tracking of debris is very accurate. Each object has a predicted collision risk based on size. Those over ten centimetres pose the greatest threat, and collision avoidance manoeuvres can be used to prevent catastrophe. When the ISS is hit by debris, the collision is often caused by relatively small objects that couldn't be predicted by the tracking system. They have been known to damage external equipment, but their small size limits the damage they're capable of causing.**

# PIP-FREE FRUITS

Dear **HIW**,
I'm unsure if it's just circumstantial or whether they're being grown differently, but there seem to be no pips in fruit these days. Why is this?
**Maia**

**There are many reasons why fruit you buy may not have pips, or seeds. Some plants undergo spontaneous genetic mutations that result in seedless fruits. These fruits are unable to reproduce, and so are unable to produce new fruit in the wild. On fruit farms, seedless fruits like satsumas can still be grown, as they are grafted. Instead of new plants growing from a planted seed, offcuts of one plant are combined with the rootstock of another citrus plant. Some fruit farms have increased the number of seedless fruits they grow due to convenience and consumer preference. Many consumers prefer to eat fruit without pips. Meanwhile, growing seedless fruits through grafting and propagation means that farmers don't have to rely on pollinators like insects as much.**

Most species of citrus fruits were not originally seedless

# HOW TO HULA

Dear **HIW**,
I've noticed that more people are using hula hooping as a form of exercise. What are the benefits of using a hula hoop and what muscles does it work?
**Holly Jones**

**This simple piece of equipment can be a fun and effective way to exercise. Keeping a steady and consistent rhythm can improve your cardiovascular fitness, increasing the ability of your heart and lungs to provide the body with oxygen. As you hula hoop, you need to keep your waist muscles activated. This can create strong core muscles and hip mobility. As you move, muscles in your mid and lower body are being worked the most: your quadriceps at the front of your thighs, hamstrings at the back and your calves and glutes. Many people who hula hoop solely for exercise purposes like to use weighted hoops. These increase the work rate of the core muscles and overall effort required.**

Hula hooping can improve balance

## NEXT ISSUE
ISSUE 160
ON SALE 20 JAN 2022

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The western Hermann's tortoise hibernates in the ground

# SLEEPING SEASON

Dear **HIW**,
What animals are currently hibernating? Also, what animal hibernates for the longest time?
**Christopher Hardy**

**Most hibernating animals do so in the winter, when temperatures plummet and food sources become sparse. In preparation, they use the autumn to stock up on food. These animals include bats, bumblebees, bears, geckos, groundhogs, hedgehogs, ladybirds and many more. Wood frogs are some of the longest hibernators. These frogs can spend seven months of the year in their deep freeze. During winter hibernation, they stop breathing and their hearts stop beating. An antifreeze substance produced in their bodies means that while they are in their frozen state, their cells survive.**

During major surgeries, patients are given medication to make them unconscious

# A CONSCIOUS THOUGHT

Dear **HIW**,
When we're asleep or put under general anaesthetic we are said to be unconscious, but what does that really mean? What is going on in the brain while we're in this state?
**Sam Milic**

**When sleeping, we're unconscious to most of the things that happen around us, but if we are put under general anaesthetic we become unresponsive to further stimuli such as very loud noises and shaking. When unconscious, segments of the brain become fragmented. As parts of the brain become isolated, they lose the ability to communicate signals across the organ to transfer information effectively.**

# WE ASKED YOU

**This month on Instagram, we asked you: Which species of bird is your favourite?**

@CATHODE149
Hooded vultures: they're so ecologically important and critically endangered

@ELLIE_M.465
**A kingfisher because of their vibrant, beautiful colours**

@BUDGET_MUMMY
**Long-tailed tits! They are little balls of fluff and so cute**

@SERINLIU
**Serin**

@DUTRZ
**Gannets, because they can dive into the water at around 60 miles per hour**

@AESTHETICALLY_AJ
**It has to be the sulphur-crested cockatoo, just for their hairstyle**

© Getty


HOW IT WORKS

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**Printed by** William Gibbons & Sons Limited
26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

**Distributed by** Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU
www.marketforce.co.uk
Tel: 0203 787 9001

**ISSN 2041-7322**



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# FAST FACTS

Amazing trivia that will blow your mind

## 13.8 BILLION YEARS

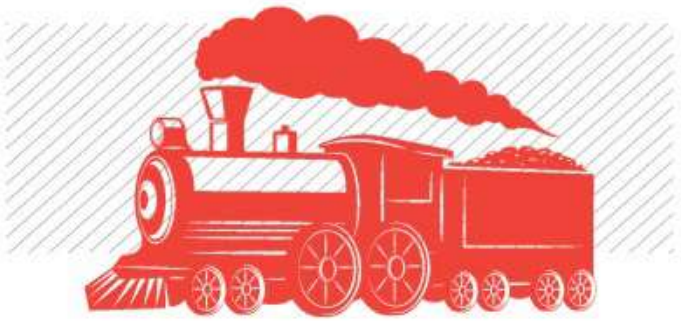
Every hydrogen atom in your body is as old as the Big Bang

## $62.5 TRILLION PER GRAM

Antimatter is the most expensive substance in the world

## 200 BEATS PER SECOND

A hummingbird beats its wings at a staggering rate



## ENGLISH NOVELIST CHARLES DICKENS HAD A PHOBIA OF TRAINS

## 1.5 SOLAR MASSES

A neutron star packs its huge mass into a sphere just 12.5 miles wide

**1978**

In this year, an electronics marketer sent the first spam email to 393 people

## £325 billion

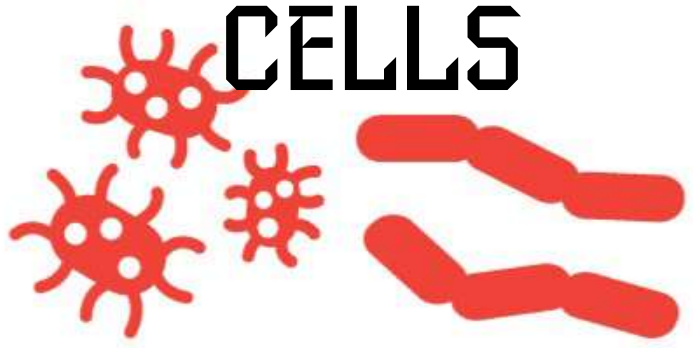
14th-century West African emperor Mansa Musa had over twice Jeff Bezos' fortune

## 1,500 YEARS

The Neolithic era was a tiny part of the 2.5-million-year Stone Age

**Women are born with all the eggs they will ever have**

## YOU HAVE TEN TIMES MORE BACTERIA IN YOUR BODY THAN HUMAN CELLS



# 2022 TOYOTA DREAM CAR ART CONTEST

Entries are open for the 2022 Dream Car Art Contest

Great prizes to be won by designing a car for the future in Toyota's Dream Car Art Contest

Toyota is giving children a great opportunity to use creativity, imagination and drawing skills to explore what the future of mobility might look like.

**Prizes include winning an iPad or a Samsung tablet, plus a Toyota goody bag. Their work will be entered in the competition's global final.**

To enter and for full details please visit:
**www.Toyota.co.uk/dreamcar**

**Entries close: 31st December 2021**

TOYOTA DREAM CAR ART CONTEST

AIRFIX

# QUICK BUILD

- Stickers Included
- Rolling Wheels
- Pre-Coloured
- Push Fit

J6036
FORD MUSTANG GT

## Ford Mustang GT
### Build an Iconic Model

The sixth generation Ford Mustang (S550) is the current iteration of the Mustang pony car manufactured by Ford. In departure from prior Mustang models, the sixth generation Mustang includes fully independent rear suspension on all models, as well as an optional 2.3L EcoBoost turbocharged and direct injected four-cylinder engine. The new Mustang was introduced as a 2015 model year vehicle, marking the fiftieth anniversary of the Ford Mustang, which was revealed as a 1965 model year vehicle on April 17, 1964. The sixth generation is also the first Ford Mustang to be marketed and sold globally, and represented the first time that factory right hand drive Mustangs were produced in addition to the left hand drive models.

**This vehicle has already become a true icon. You can create your own version at home with this Airfix QuickBuild kit. Recreate brilliant scale models of a wide variety of iconic aircraft, tanks and cars with QuickBuild kits. No paint or glue is required, the push together brick system results in a realistic, scale model that is compatible with other plastic brick brands.**

**No glue!**
**No paint!**
**Just build!**

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J6025 Yellow VW Beetle

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